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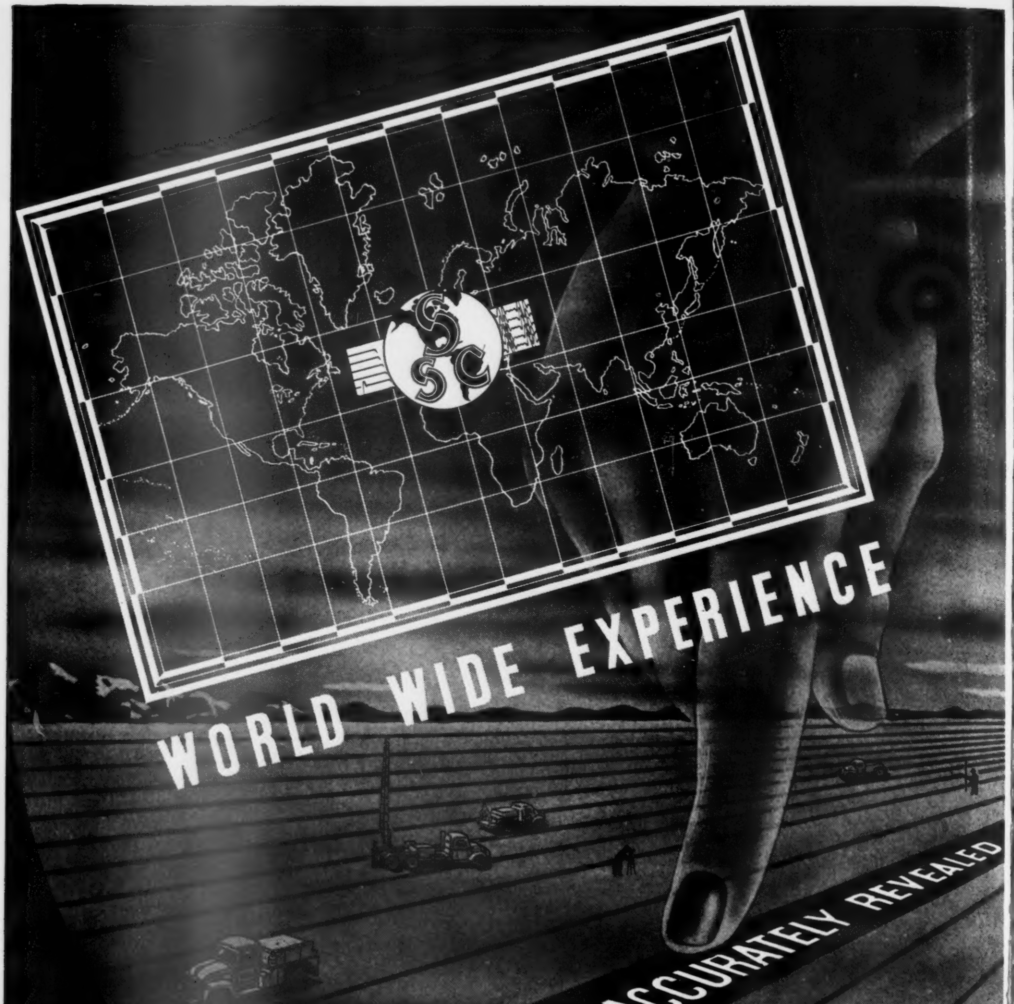
BULLETIN
of the
American Association *of* Petroleum Geologists

CONTENTS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BULLETIN

of the

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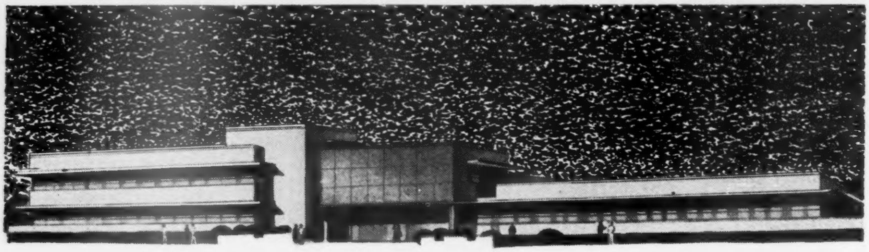

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of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

OCTOBER, 1948

SANTA ANA, SAN JOAQUÍN, GUARIO, AND SANTA ROSA OIL FIELDS (ANACO FIELDS), CENTRAL ANZOÁTEGUI, VENEZUELA[1]

H. J. FUNKHOUSER,[2] L. C. SASS,[3] AND H. D. HEDBERG[4]
Venezuela and New York

ABSTRACT

The Santa Ana, San Joaquín, Guario, and Santa Rosa oil fields, which may be grouped together as the Anaco fields, are in the central part of the state of Anzoátegui in eastern Venezuela. Since the completion of the discovery well of the Santa Ana field in 1937, five additional domes have been drilled and found productive. As of January 1, 1947, 71 wells have been drilled, resulting in a production of more than 27,000,000 barrels and a daily potential of 22,650 barrels.

The six drilled domes of the Anaco area have a northeast-southwest trend and extend over a distance of 30 miles. The four southwestern domes are indicated on the surface by outcrops of middle Miocene beds surrounded by upper Miocene-Pliocene beds, but older beds of the two northeastern domes are completely and unconformably covered by the younger beds. The closest known seepage is

[1] Manuscript received, June 10, 1948.

[2] Mene Grande Oil Company, Caracas, Venezuela.

[3] Mene Grande Oil Company, Caracas, Venezuela.

[4] Gulf Oil Corporation, New York. Formerly with Mene Grande Oil Corporation, Caracas, Venezuela.

Acknowledgments.—Inasmuch as four companies (Creole, Socony, Texas, and Mene Grande) are operating in the several fields of the Anaco trend, contributions to the growth of information since 1934 have been made by a considerable number of geologists, geophysicists, and engineers. It is obviously impractical to mention all of these individually by name. The writers wish particularly to acknowledge the work of P. E. Nolan and George Lockett, respectively chief geologist and assistant chief geologist of the Mene Grande Oil Company, in their development of information on this area. Other Mene Grande geologists who have contributed are the following.

Stratigraphy: Georges Pardo, Augustin Pyre, R. B. Van Buren
Subsurface geology: Grady Davis, Henry Guntz, R. S. Mahoney, Carlos Vogeler
Core and fluid analysis: G. E. Manger
Surface geology: Philip Andrews, A. J. Krumholz, Cliff Peery, Roy Wilson
General: E. E. Brossard

The geological staffs of the New York and Pittsburgh offices of the Gulf Oil Corporation and the geophysicists and engineers of the Gulf Research and Development Corporation have also made many important contributions. With regard to other companies, the writers are familiar with some of the work done by L. T. Hart, M. W. Haas, and F. W. Johnson of the Creole; Frank LeRoy, H. L. Tipsword, and H. J. Maiers of the Socony; and M. W. Zaikowsky of The Texas Company.

This report on the Anaco fields is published with the approval of C. M. Crebbs, president, Hoyt Sherman, vice-president, and Robert Boggs, division manager, of the Mene Grande Oil Company. The other operators in the area, the Creole Petroleum Corporation, the Socony-Vacuum Oil Company of Venezuela, and The Texas Company, have also granted permission for publication.

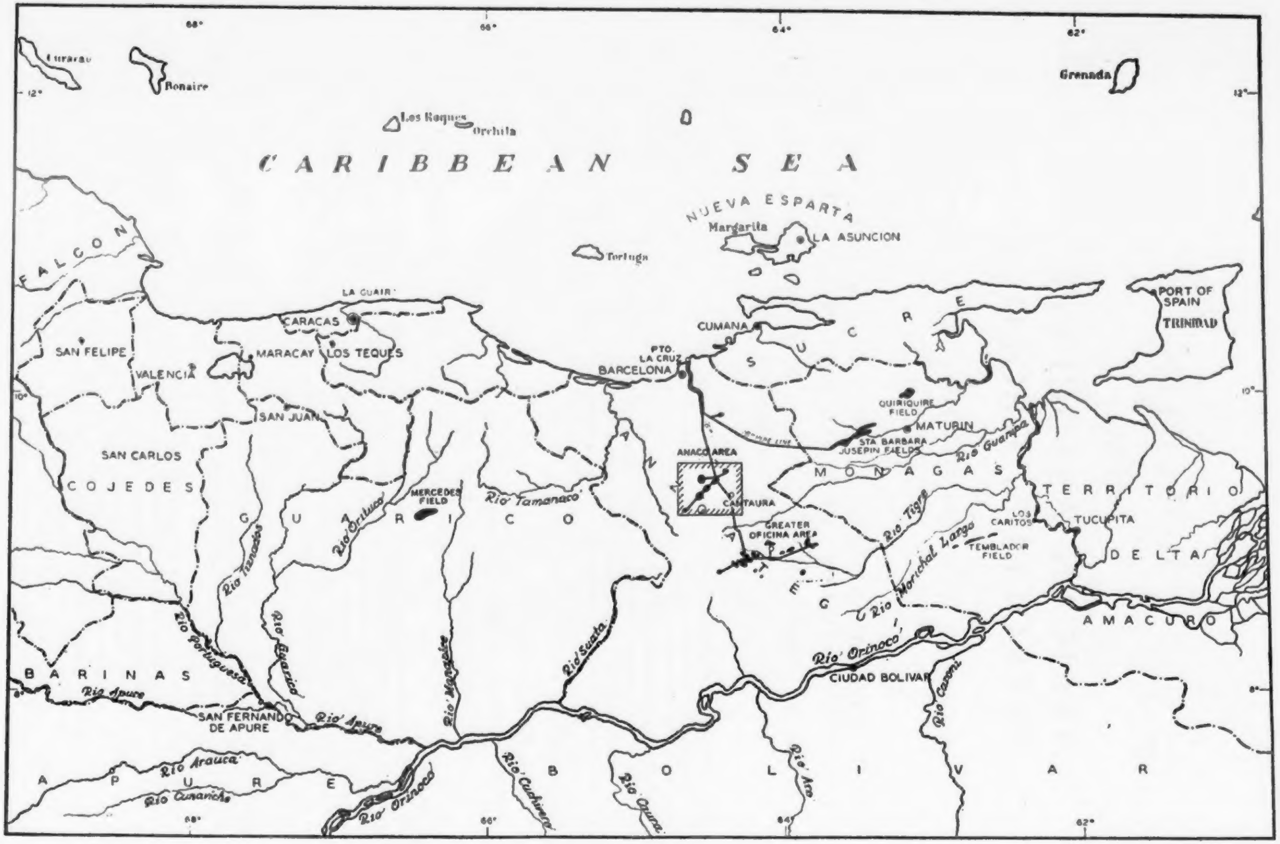


FIGURE I - INDEX MAP

more than 35 miles distant. The discovery well was located on surface and aerial geology and the remaining domes were drilled on such information plus reflection seismograph excepting for the two northeast domes which were based on reflection seismograph alone. Subsequent development has been guided mainly by reflection-seismograph and subsurface geological work.

The section encountered by wells in the Anaco fields is as follows.

Sacacual group (upper Miocene-Pliocene). 0–1,600 feet thick

Unconformity

Freites formation (middle Miocene). 0–2,100 feet thick

Possible unconformity on structural highs

Oficina formation (Oligocene-Miocene). 7,500–10,000 feet thick

Merecure formation (upper Eocene-lower Oligocene). More than 1,900 feet thick (base not yet reached)

All of the Anaco domes are asymmetrical with steep (as much as 80°) southeast flanks and relatively gentle (as much as 25°) northwest flanks; the several domes are separated by saddles or by sharp synclines which are probably faulted. All the domes are believed to be formed by drag over a northwest-dipping zone of thrust faulting. Most of the domes are relatively simple with only a few normal faults but the Santa Rosa dome is noteworthy because of its many normal and reverse (strike-slip) faults. Accumulation is mainly controlled by the structural closure of the domes with sand lenticularity of some importance in localizing the accumulations. Some oil has been produced from the first beds below the thrust fault.

Production is from sands in the Oficina and Merecure formations. Twenty-eight Oficina sands have produced oil and at least 15 additional Oficina sands have so far tested gas at high positions. In the oil-productive part of the Oficina formation only 8 per cent of the section consists of sandstone beds. In the Merecure formation, which consists of 50 per cent sandstone and 50 per cent shale and claystone, it is possible that only one reservoir is present in any one segment; in other words, the many sands may have complete connection with each other. Where tested, the Merecure formation has been gas- or oil-productive without exception. Oil-productive depths range from 3,830 to 10,705 feet, and gas accumulations have been encountered just below the surface. The total productive surface area amounts to nearly 29,000 acres.

Reservoir pressures in the Oficina formation are locally 500–1,000 pounds per square inch in excess of hydrostatic pressure, whereas Merecure pressures are essentially in accord with hydrostatic pressure. The temperature gradient averages about 44 feet per 1°F., and the maximum recorded temperature is 276°F. All production to date has been either 33–47° API wax oil or 44–57° API condensate, the latter accounting for only 2 per cent of the total. The wax oils have a wax content of about 15 per cent by weight and a pour point of about 85°F. Apparently all reservoirs have gas caps and some reservoirs contain gas only. One oil zone has a thickness of 1,400 feet. Formation waters range from only 1,500 to 5,000 parts per million of chloride ion through the Oficina formation but show a marked increase in salinity to 15,000–18,000 parts per million of chloride ion in the Merecure formation.

Dual-zone completions are common practice and for the past several years only one sand has been perforated in each zone. All recent completions have been through gun perforations. Well spacing is on the equilateral triangle system and varies from 25 to 126 acres or more; boundary and structural adjustments have locally caused close spacing but only a small part of the productive area has been drilled. Pressure-maintenance projects are being discussed. The outlet of the fields is through the 155-kilometer 16-inch pipe line extending from the Greater Oficina area through the Anaco area to Puerto La Cruz on the Caribbean coast.

INTRODUCTION

One of the outstanding features of the eastern Venezuela basin is a prominent regional structural high cutting transversely across it from northeast to southwest in the central part of the state of Anzoátegui. A series of domes along this structural axis has given rise to the Santa Ana, San Joaquín, Guario, and Santa Rosa oil fields extending in a narrow belt a distance of nearly 50 kilometers along this trend. These fields are unified by marked similarities in stratigraphy, structure, and producing characteristics and may be conveniently grouped under the name of the Anaco fields (Fig. 1). This name is derived from the Anaco tank farm and pump station which serves all of these fields. To January 1, 1947, they

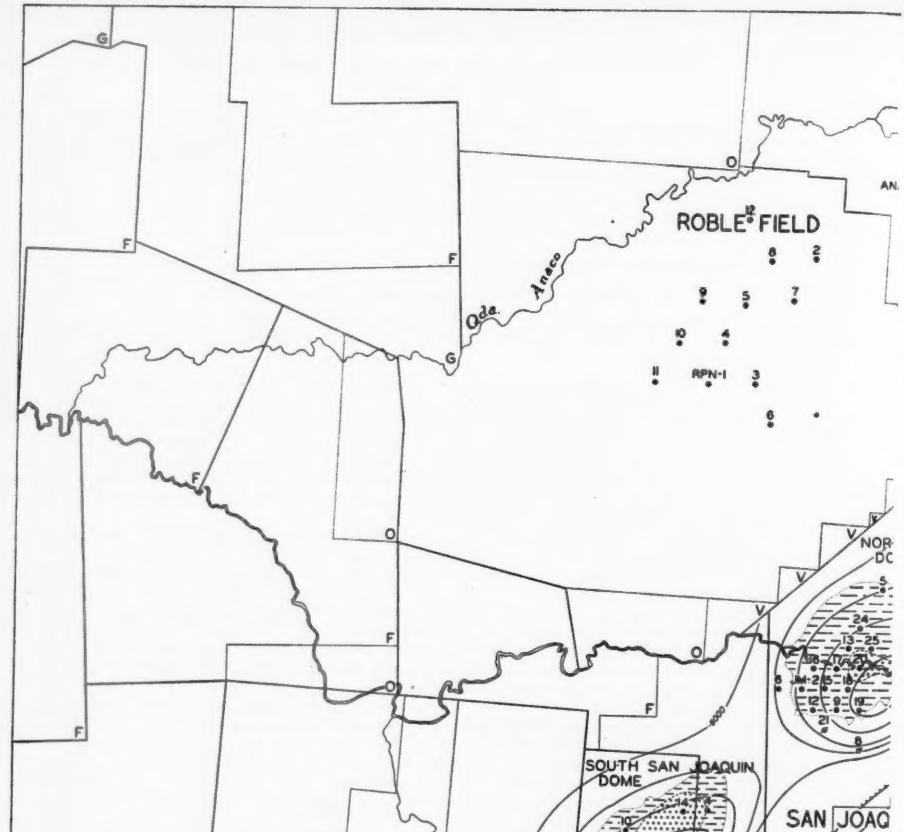
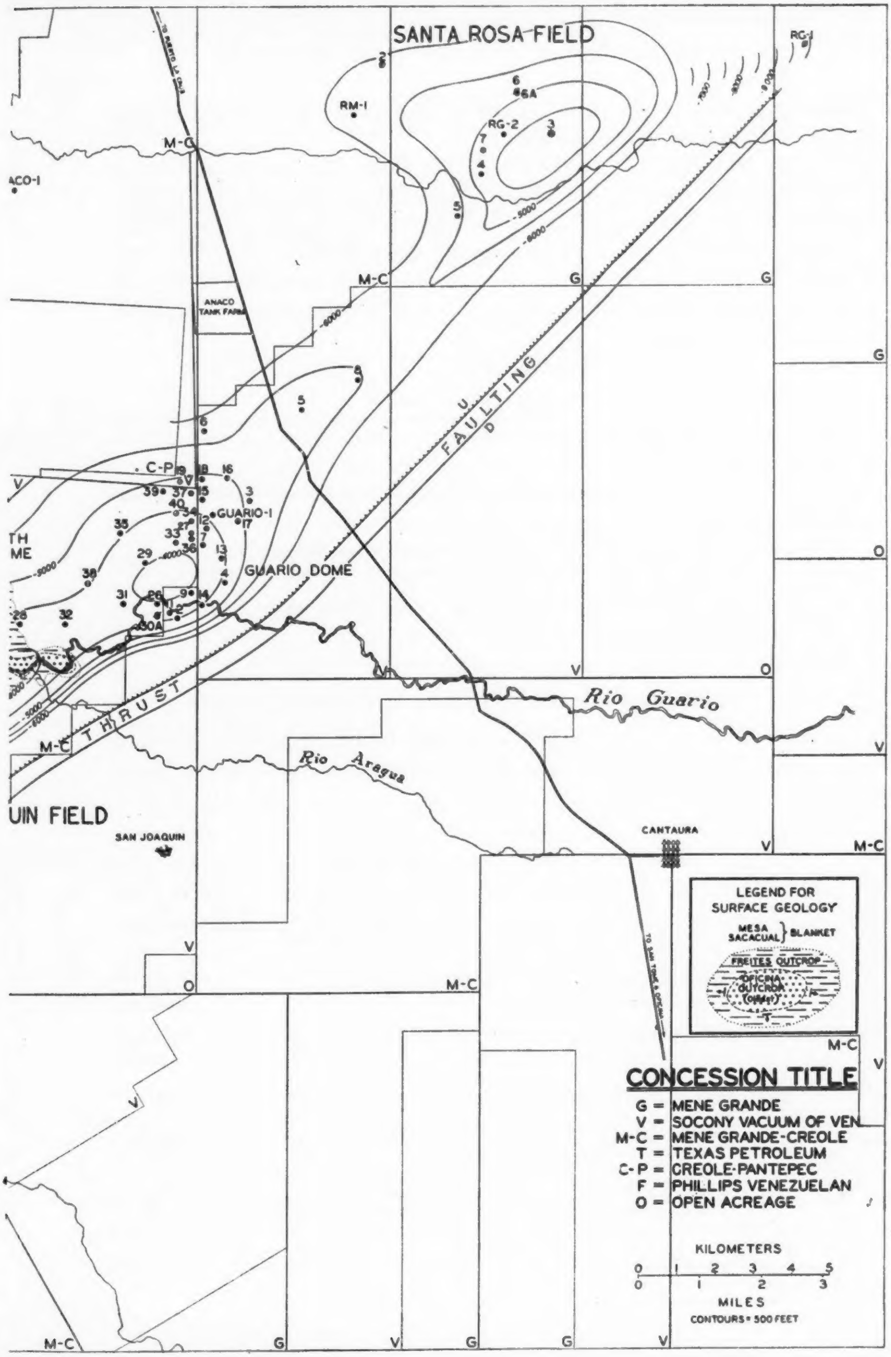


FIG. 2.—General map of Anaco area, including



top of Verde contours and surface geology.

had produced 27,000,000 barrels of oil and at that time had a daily potential production of more than 22,500 barrels.

The Roble field, operated by the Creole Petroleum Corporation and under joint Creole-Pantepec ownership, is closely associated stratigraphically and geographically with the four fields. It is not included in this report, partly because it is a simple monocline, therefore structurally much different from the other fields, partly because it lies in a flank position, somewhat northwest of the axis of the main structural trend, but mainly because it is to be described in a separate report by another company.

Major Features

1. Dome structures associated with major line of thrust faulting
2. Moderate dips (0°–25°) excepting locally along southeast flank where dips of 50°–80° are associated with controlling zone of thrust faulting
3. Normal faulting of minor importance
4. Multiple productive sands
5. Production from Oligocene-Miocene Oficina formation and from Eocene-Oligocene Merecure formation
6. Oil-producing depths, 3,800–11,000 feet
7. Production consists of light oils (33°–47° API) and condensate. No heavy oils
8. All oils characterized by high wax content (±15 per cent) and high pour point (±85°F.)
9. Intermediate paraffine-base oil
10. All reservoirs have gas caps and several sands have yielded nothing but gas
11. Relatively hard drilling
12. High temperatures (200°–300°F.)
13. Dual-zone completions

ACREAGE OWNERSHIP AND NOMENCLATURE OF FIELDS AND WELLS

The Anaco trend comprises the following fields from southwest to northeast (Fig. 2): Santa Ana field, San Joaquín field (South dome, North dome, Guario dome), and Santa Rosa field.

TABLE I

Classification of Oil Fields in Anaco Area

Field or Dome	*Owner*	*Operator*	*Wells Drilled**	*Wells Drilling**	*Well Designation*
Santa Ana	Mene Grande-Creole	Mene Grande	4†	2	AM
	Texas Petroleum Co.	Texas	4	0	Rincón
South San Joaquín	Mene Grande-Creole	Creole	9	0	JMN and JM
North San Joaquín	Mene Grande-Creole	Creole	18	0	JM
Guario	Socony-Vacuum of Venezuela	Socony-Vacuum	17	1	Guario
	Mene Grande-Creole	Creole	11	2	JM
Santa Rosa	Mene Grande	Mene Grande	6	1	RG
	Mene Grande-Creole	Mene Grande	2	0	RM
			71	6	

* January 1, 1947.
† Includes 1 suspended, awaiting fishing tools.

Mene Grande-Creole wells are designated by letters indicating the field (first letter) and ownership (second letter M indicates Mene Grande-Creole pooled acreage and G indicates Mene Grande solely owned acreage) and are numbered consecutively in order of drilling in each ownership group. All Mene Grande-Creole wells in the San Joaquín domes have the same letter designation (JM), excepting where they are drilled on leases acquired from national reserves, where they are designated as JMN. Texas Company wells are not abbreviated and are named Rincón No. 1, No. 2, *et cetera*. Socony wells are also not abbreviated and are named Guario No. 1, No. 2, *et cetera* (in this group Guario No. 10 was not drilled). Table I summarizes pertinent details on the fields and domes.

DISCOVERY

The first well to be drilled near the Santa Ana-San Joaquín-Santa Rosa trend was Santa Rosa No. 1 (RG-1). This location was based on a suggested high indicated on a single refraction-seismograph line which was run through this area in 1931. The well was spudded by the Mene Grande Oil Company on February 14, 1934, and after numerous vicissitudes was plugged and abandoned on May 8, 1936, after having reached the final depth of 7,214 feet. The only indication of petroleum was a small gas showing at 5,800 feet. The principal function served by this well was the providing of an excellent cored section, which was subsequently of great value in determining the stratigraphy of the general region. Additional seismograph work from November, 1933, to January, 1934, showed that the location was off structure on the east of a prominent high (Santa Rosa dome) and still more recent seismograph work and drilling has made it clear that this first well was far down the east flank of the Santa Rosa structure.

The actual discovery of the Santa Ana-San Joaquín trend took place in the spring of 1934, when, as a result of air-photograph study and surface geological reconnaissance, the Santa Ana and San Joaquín domes were outlined. The surface geology of the Santa Ana structure was mapped in detail in the fall and winter of 1935. A small reflection-seismograph program in January and February, 1936, checked the presence of the western Santa Ana dome at depth. This work also included the coring of three seismograph shot holes for stratigraphic information.

On February 9, 1936, Santa Ana No. 1 (AM-1) was spudded by the Mene Grande Oil Company on the west dome of the Santa Ana structure. A continuous coring program was adopted. A few slight indications of gas and oil were encountered near the surface in this well and several sandy intervals gave faint chloroform colorations. The section in general, however, was lacking in sands and was considered discouraging until a thin well stained oil sand (Verde B) was encountered at 4,668–4,678 feet. No test was made. At 5,987–6,011 feet thin sands with faint oil staining and a good gassy odor were encountered. The well was drilled to 6,100 feet and $8\frac{5}{8}$-inch casing was set at 5,973 feet. A test of the open hole showed wet gas under high pressure, but with little volume. Drilling

was resumed and at 6,142 feet the well entered a large sand body (Colorado C sand). Cores had a good odor, but no staining and gave only a very faint cut. On October 14, the well blew out with gas while still coring in sand at 6,187 feet. It was quickly controlled and drilling continued to 6,207 feet. Perforated liner was run and a test was made of the open interval, 5,973–6,207 feet, which showed the well capable of producing 12 million cubic feet of gas per day with a yield of 675 barrels per day of 54° API condensate.

HISTORY OF EXPLORATION AND DEVELOPMENT

During 1935 and 1936, Creole and Mene Grande geologists carried out detailed surface work over the San Joaquín domes and the Santa Ana structure, and during the drilling of AM-1 laboratory correlation was established in the Oficina formation with Santa Rosa No. 1 and in a general way with wells in the Oficina field. At the same time, both the Creole and Mene Grande made extensive reflection-seismograph surveys so that by 1937 a fairly good general picture of the Santa Ana-San Joaquín-Santa Rosa line of folding had been obtained.

In February, 1937, drilling was resumed in AM-1 and the well was drilled from 6,207 feet to the final depth of 7,628 feet. Numerous very hard petroliferous sandstones were encountered and the well was finally stopped because of the difficulty of making more hole. Casing was run to 7,500 feet and the well was brought into production in December from the sand interval from 7,500 feet to the bottom (Merecure formation), making 3 million cubic feet of gas and 50 barrels of condensate.

Santa Ana No. 2 (AM-2) was spudded by the Mene Grande Oil Company on the east Santa Ana dome in January, 1938, and established the presence of numerous wet gas sands on this structure. Santa Ana No. 3 (AM-3) started on the north flank of the west dome in May, 1938, and was completed in April, 1941, as the first oil well in the Santa Ana field, producing 666 barrels per day of 34° API oil through a $\frac{1}{4}$-inch choke from the interval of 8,320–8,335 feet in the Merecure formation. Four additional oil wells have been completed by The Texas Company in the Rincón area on the south flank of the structure during the period from 1941 to 1947. No additional wells were completed by the Mene Grande during this period although one (AM-4) is at final depth awaiting fishing tools.

In May, 1938, JMN-1, the first location on the San Joaquín south dome was spudded by the Creole and in June of the same year JM-2 was spudded by the Creole on the north San Joaquín dome. JMN-1 was completed in April, 1939, initially producing 850 barrels of 39° API oil through a $\frac{1}{2}$-inch choke and JM-2 was also completed a month later, initially producing 1,338 barrels of 37° API oil through a 19/32-inch choke. These wells opened the south and north San Joaquín domes, respectively, and to date 9 wells have been drilled on the south dome and 18 on the north dome.

The first well on the Santa Rosa dome was RG-2 which was begun by the

Mene Grande Oil Company in May, 1940, 8 kilometers southwest of the first Santa Rosa well (RG-1). RG-2 was successfully completed on January 24, 1941, initially producing 715 barrels of 42° API oil through a $\frac{1}{4}$-inch choke. Five oil wells have been completed on this structure and three wells (one with many gas sands) have been abandoned.

The Guario dome was opened to production by the Socony Vacuum Oil Company with its Guario No. 1, which was spudded on September 28, 1939, and completed in September, 1940. The initial production test showed 695 barrels of 40° API oil through a $\frac{1}{4}$-inch choke with a gas-oil ratio of 1,868 cubic feet per barrel. Subsequently, the Socony has drilled 16 wells on this dome, while the Creole has drilled 11 wells on the Mene Grande-Creole pooled leases adjacent to the Socony property.

Table II lists the various wildcat and exploratory step-out wells (more than 1 mile from production) drilled in the development of the Anaco area to date and includes some essential information on each well. The well locations are shown in Figure 2. Of the 18 wells classified as wildcats or long exploratory step-outs, only 2 have been abandoned as dry holes.

During the course of the drilling development, and subsequent to the early investigations previously mentioned, various additional exploration projects have been carried out by the Creole, Socony, Texas, and Mene Grande companies. These included detailed reflection-seismograph surveys, magnetometer and gravimeter work, surface geological work, and structure drilling. At present (January 1, 1947) drilling activity in these fields is rather low and is summarized as follows.

Santa Ana: 2 Mene Grande rigs drilling AM-5 and AM-6
San Joaquín (South): no drilling
San Joaquín (North): no drilling
Guario: 2 Creole rigs drilling JM-38 and JM-40
　　1 Socony rig drilling Guario No. 19
Santa Rosa: 1 Mene Grande rig drilling RG-7

SURFACE FEATURES

Physiography.—The Anaco trend is west of the western edge of the great Eastern Venezuelan mesa. It is thus in the topographically low, dissected, brush- and tree-covered area of Eastern Venezuela, known as the "monte," as contrasted to the high flat grass-covered plains of the "mesa."

Drainage along the whole line of fields is westward into the Guere River which in turn flows northwestward into the Unare River, which finds its outlet northward into the Caribbean Sea west of Puerto Píritu. The principal water courses crossing the Anaco trend in order from south to north are the *quebradas:* Misacantada, Guere, Meria, Guaro, Chiguapo, Orocopiche, Aragua, Guario, and Anaco. These in general head in the mesa scarp on the east and derive a large part of their water supply from the Mesa formation sands and gravels exposed along this scarp. Most of these streams are intermittent throughout large parts

TABLE II

DATA ON WILDCAT AND EXPLORATORY STEPOUT WELLS IN THE ANACO FIELDS

Well Designation	Field	Dome	Kilometers from Previous Completion	Spudded	Completed	Total Depth	Number of Gas or Oil Sands	Net Gas or Oil Sand	Over All Productive Section	Name of Producing Sand	Producing Interval	Initial Prod. Bbls. per Day	Choke	API Gravity	Flowing Pressure	Gas Oil Ratio (Cu Ft. per Bbl.)	Remarks	Production to January 1, 1947	Basis for Location
RG-1	Santa Rosa	--	140 Quiriquire	2-14-34	5-8-36	7214'	-	-	-		-	-	-	-	-	-	Abandoned	-	Refraction Seismo.
AM-1	Santa Ana	South	190 Quiriquire	2-9-36	11-7-37	7628'	9	210	4850-7628	Merecure	7500-7628'	80	1/4"	51	2576	97,700	Reworked to VerdeB	160,186	Air & Surface Geology
AM-2	Santa Ana	North	5.2:AM-1	1-15-38	5-7-40	8840'	7	800'	5433-8840'	Colorado H	7030-7040'	985	5/8"	49.8	2025	14,190	Condensate well	70,608	Above & Reflection Seismo.
AM-3	Santa Ana	South	1.6:AM-1	5-14-38	4-21-41	8988'	4	325'	6716-8450'	Merecure	8320-8335'	666	1/4"	33.4	1050	780		754,575	Above & Reflection Seismo.
JMN-1	San Joaquin	South	14.7:AM-1	5-15-38	4-4-39	6040'	5	140'	4247-7155'	Verde G	5976-6040'	850	1/2"	39.0	300	750	Deepened to 7212' Recompleted in Verde-I & G	801,405	Surface & Reflection Seismo.
JM-2	San Joaquin	North	22.3:AM-1	6-18-38	5-8-39	6414'	3	75'	5790-6407'	Verde I	6370-6414'	1338	19/32"	37	600	-		368,077	Surface & Reflection Seismo.
Rincon-1	Santa Ana	?	2.7:AM-1	2-1-39	10-19-41	9632'	4	155'	7938-8790'	Colorado H Merecure	7947-8056' 8775-8790'	384 566	1/4" 1/4"	38.1 35.6	1000 1190	1475 844		95,378	Reflection Seismo
JM-4	San Joaquin	South	3.8:JMN-1	6-8-39	10-5-39	6625'	2	45'	4330-6178'	Verde I	6153-6175'	701	1/4"	40.8	1575	-		1,474,628	Reflection Seismo
JM-5	San Joaquin	North	3.3:JM-2	7-16-39	12-9-40	9437'	4	200'	6230-9437'	Verde E Amarillo C?	6230-6285' 7042-7060	229 285	1/4" 1/4"	36 41	1000 480	2164 400		115,830	Reflection Seismo
Guario-1	San Joaquin	Guario	8.9:JM-2	9-28-39	9-12-40	8297'	6	90'	5087-8242'	Colorado A(E,F,)	6870-7165'	695	1/4"	39.8	2075	1888		295,745	Reflection Seismo
JM-6	San Joaquin	North	2.2:JM-2	10-25-39	1-8-41	10,124	-	-	-	-	-	-	-	-	-	-	Abandoned		Reflection Seismo
JMN-7	San Joaquin	South	2.4:JMN-1	10-31-39	10-21-40	9519'	1	30'	9150-9181'	Colorado R ?	9150-9160'	743	1/4"	38.0	1825	1893		642,392	Reflection Seismo
Guario-2	San Joaquin	Guario	7:JM-2	3-15-40	2-11-41	8000'	6	215'	3710-7863'	Colorado A	6868-6873	1158	5/16"	39.6	1875	1646		86,518	Reflection Seismo
RG-2	Santa Rosa	-	19:RPN-1	5-8-40	1-24-41	6577'	16	290'	2793-6550'	Verde J	6535-6550'	715	1/4"	42.0	2000	2030	Reworked to Verde E & Fu	973,821	Reflection Seismo
RM-1	Santa Rosa	-	4:RG-2	5-18-41	7-10-42	9611'	4	95'	5800-8970'	Naranja H	5816-5824'	690	5/16"	45.7	850	875		218,495	Reflection Seismo
Guario-5	San Joaquin	Guario	3.6:G-1	12-14-41	11-4-42	10,615	4	575'	6375-10,615	Colorado K & R	8290-8340' 8972-8994'	617	5/16"	45.8	2350	4600	Reworked to include Merecure	442,385	Reflection Seismo
Guario-6	San Joaquin	Guario	2.2:G-1	8-23-42	9-20-43	10,521	1	155'	9890-10,270	Merecure	10,005-10,08[illegible]	[illegible]	5/16"	52.3	2580	15,898		172,792	Subsurface & Seismo
Guario-8	San Joaquin	Guario	1.7:G-5	12-18-43	11-18-44	10,735	5	400'	6918-10,735	Merecure H & I Merecure J	10,420-10,575 10,66010,705	256 941	5/16" 5/16"	49.9 42.9	2150 1900	12,787 2131	Reworked to V-H & C-K	178,069	Subsurface & Seismo

of their courses, but flow is frequently continuous below the surface in the deep sand of their beds.

The elevation of the area ranges from 500–600 feet in the Santa Ana, San Joaquín, and Guario fields, to more than 700 feet in the Santa Rosa field. It is thus considerably lower than the mesa on the east which has an elevation of as much as 900–1,000 feet. The area is intricately dissected by the *quebradas* and their tributaries, but relief in any field as indicated by well elevations is less than 100 feet and the maximum relief in the whole area is probably little more than 300 feet.

Climate.—The climate is uniformly warm. Average daily maximum temperatures range between 90°F. and 95°F. every month of the year. The temperature drops to approximately 70°F. every night. The air is dry and still, the trees and brush of the "monte" restricting near-surface air movements. There is a rainy season from May to November, and approximately 90 per cent of the annual precipitation occurs in this period. The annual rainfall averages 48 inches.

The summary of average monthly temperatures and average monthly rainfall is based on records covering an 8-year period of daily observations by the geological department of the Socony Vacuum Oil Company at its Guario camp.

Month	*Average Daily Minimum Temperature*	*Average Daily Maximum Temperature*	*Average Monthly Rainfall (Inches)*
January	66.9°F.	91.6°F.	0.37
February	68.8	92.5	0.37
March	70.0	94.0	0.56
April	72.7	95.1	1.06
May	72.4	94.1	4.26
June	70.7	91.2	5.81
July	69.4	90.1	8.70
August	69.7	92.8	8.32
September	69.4	93.4	4.99
October	69.7	93.3	7.04
November	69.1	93.0	4.70
December	68.4	91.3	1.81
			47.99

Geography.—Before the beginning of oil-field development, the area was exclusively agricultural. It was very sparsely settled then and still remains so away from the oil-field centers. The inhabitants depended largely on livestock and small fields of yucca, plátanos, and corn for their subsistence. The only towns of importance were the villages of San Joaquín, Santa Ana, and Cantaura. Communication with the outside world was largely by means of a poor road connecting Aragua de Barcelona and Ciudad Bolivar which passed near the area of the southern San Joaquín dome and along which there was also a telegraph line. Travel, excepting along this road, was by means of horses and burros on small "monte" trails.

During the drilling of Santa Ana No. 1, a road was built to connect that well with the Oficina field and El Tigre, 60 kilometers southeast. However, with the development of the Oficina field, the highway connecting it with the oil-shipping terminal at Puerto La Cruz on the Caribbean coast, and passing between the Guario and Santa Rosa domes, has now become the principal outlet for the area. All fields are now directly connected with this highway by improved roads.

The populations of the towns of San Joaquín, Cantaura, and Santa Ana have increased considerably by the influx of oil-field workers and there are fairly large company camps at Buena Vista (Creole) and Anaco (Socony), besides smaller camps at Anaco (Mene Grande), on the Guario dome (Socony), the Santa Ana field (Texas and Mene Grande), and the Santa Rosa field (Mene Grande). There is an air field at Anaco which is served by commercial airlines.

Areal geology.—The surface distribution of formations along the Santa Ana-Santa Rosa trend is shown in Figure 2. Most of the area is covered by claystones and sandstones of the non-marine Sacacual group of upper Miocene-Pliocene age. Along the axis of the structural trend, however, the older Freites and Oficina formations of Miocene and Oligocene-Miocene age are locally exposed on the Santa Ana and San Joaquín domes. These older formations do not crop out on the Guario or Santa Rosa domes which are completely blanketed by the Sacacual. Isolated patches of Mesa formation (Pleistocene) are scattered over the Sacacual outcrop area in the vicinity of the main mesa front, and the more extensive Mesa formation occurs in the vicinity of the Anaco tank farm north of the Guario dome. This mesa area is characterized by an open grassy plain with scattered chaparro trees in contrast to the more densely wooded areas of the older formations.

Surface indications of oil and gas.—No oil seepages are known anywhere along the Anaco trend. However, thin sand laminae stained with heavy oil were noted at a depth of only 200–300 feet in Santa Ana No. 1 and in several core-drill holes on the Santa Ana structures. Several seismograph shot holes on the San Joaquín and Santa Rosa structures showed gas. One hole flowed for several days at an estimated daily rate of 700,000 cubic feet from a depth of 105 feet. Two small semi-active mud volcanoes associated with springs have been reported 4 kilometers north of the village of San Joaquín.

STRATIGRAPHY

REGIONAL

The several fields along the Anaco trend are unified by remarkably similar stratigraphy and the same stratigraphic units are recognized throughout (Figs. 4 and 11). The oldest formation known in any of the fields is the Merecure formation[5] of Eocene-Oligocene age. It has been penetrated to a considerable depth in all fields, but its base has not been reached. It has been productive of oil or gas

[5] H. D. Hedberg, "Stratigraphy of Río Querecual, Northeastern Venezuela," *Bull. Geol. Soc. America*, Vol. 48, pp. 1971–2024, incl. 9 pls. and 2 figs.

in all of the domes along the Anaco trend excepting in the South San Joaquín dome where only one well has barely reached the top of the formation. The Merecure formation is overlain everywhere by the Oligocene-Miocene Oficina formation,[6] which comprises the bulk of the section in all fields and also includes most of the petroliferous intervals. It is composed of shallow marine to brackish-water shales and sandstones representing material deposited in the west part of the subsiding Eastern Venezuelan geosyncline during Oligocene-Miocene time. This formation is exposed at the present erosion surface on the Santa Ana and San Joaquín domes.

The Freites formation,[7] a dominantly marine unit of middle Miocene age, follows stratigraphically above the Oficina formation, but is poorly known in this area as it has been either partly or completely eroded from the structurally high areas where the fields are situated. Unconformably overlapping all older formations though missing at the crests of the Santa Ana and San Joaquín domes due to late Tertiary and recent erosion, is the Sacacual[8] group of non-marine claystone and sandstones of upper Miocene-Pliocene age. These sediments are widespread on both flanks of the Anaco uplift. Small patches of Mesa formation of Pleistocene age occur as outliers unconformably overlying Sacacual sediments.

More detailed data on the character of each formation known in the area are here summarized in descending stratigraphic position (order of penetration by drill).

MESA FORMATION

This formation is named from the widespread flat topographic feature known throughout Eastern Venezuela as the "mesa" which is largely composed of sediments of this formation.[9] It is poorly represented in the Anaco area where it is known only near the Anaco pump station and as a few isolated remnants between the true mesa front and the axis of the Anaco uplift. It consists largely of poorly consolidated sandstones, gravel beds, and mottled ferruginous sandy claystone and is probably no more than 100 feet thick in this area. Blocks of ferruginous conglomerate of local occurrence may represent residuals of cemented parts of the previously existing mesa cover.

SACACUAL GROUP

This name is derived from Quebrada Sacacual, a tributary of the Unare River, which heads a short distance northwest of the Santa Rosa field. It is used as a general group name for the fresh- to brackish-water upper Miocene-Pliocene sediments of Eastern Venezuela below the Mesa formation and above the upper-

[6] The Oficina formation is described in more detail in "Oil Fields of the Greater Oficina Area, Central Anzoategui, Venezuela," by H. D. Hedberg, L. C. Sass, and H. J. Funkhouser, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31, No. 12 (December, 1947), pp. 2089–2169.

[7] H. D. Hedberg, L. C. Sass, H. J. Funkhouser, *op. cit.*

[8] *Ibid.*

[9] *Ibid.*

most definitely marine Miocene beds. Sediments of this group flank the Anaco uplift on both sides and constitute the surface formation over the crests of the Santa Rosa and Guario domes and in the saddles between the two San Joaquín domes and between the southern San Joaquín dome and the Santa Ana domes. Some thickness of this group is penetrated by all wells in the Santa Rosa and Guario fields and by edge wells in the San Joaquín field.

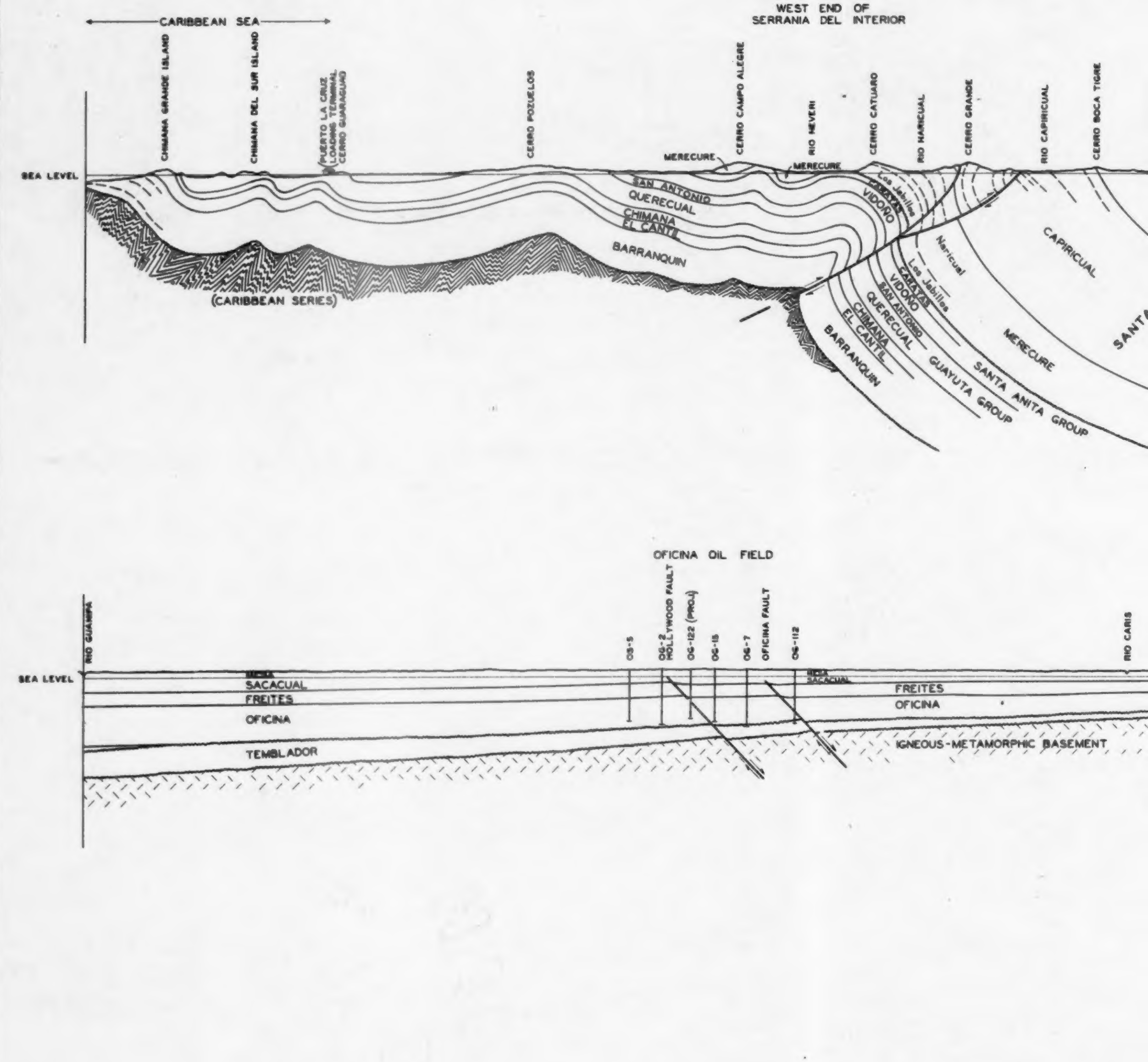
Local facies differences have been responsible for separation of the Sacacual sediments into a number of individual formations. In the area extending northwestward from the mesa front across the Santa Ana and San Joaquín fields and nearly as far east as the Puerto La Cruz-Oficina highway, the Sacacual may be divided into an upper unit (Algarrobo formation) and a lower unit (Las Piedras formation) comparable with the division in the Greater Oficina area.[10] The Algarrobo facies is confined to the area near the edge of the mesa and consists of predominantly light gray thin-bedded sandstones and interlaminated fine-grained sandstones, siltstones, and clay shales. Sediments of the Las Piedras formation are somewhat more consolidated, slightly darker in color (grays and greens), and more persistently bedded. Lignites are common. A series of massive sandstones, developed in the lower part of the formation in the vicinity of the Santa Ana field and northward, provides horizons easily traceable on aerial photographs (note light-colored bands, Fig. 7).

In the northeastern part of the area, beyond the Puerto-La Cruz-Oficina highway, there is a considerable facies change in the Sacacual sediments. The Algarrobo formation grades into a facies consisting predominantly of tan-brown claystones with some claystones mottled in tan or red and light gray. This is known as the Quiriquire formation. Unconformably below the Quiriquire beds and equivalent to the upper part of the Las Piedras formation is the Prespuntal formation of red- to lavender-weathering gypsiferous claystones with some sandstone and conglomerate. Below the Prespuntal formation is the remainder of the Las Piedras formation.

The thickness of the Sacacual group near the edge of the mesa front southeast of the Santa Ana field is about 1,500 feet and in Santa Rosa No. 1, off the eastern edge of the Santa Rosa structure, a thickness of 1,600 feet is present. However, due to post-Sacacual erosion the thickness penetrated by wells in the Anaco fields is considerably less. Thus, in the Santa Rosa field the thickness of Sacacual sediments above the Oficina formation ranges from 670 to 945 feet, on the Guario dome it is about 500 feet thick, and it is completely absent from the crestal area of the north and south San Joaquín domes and the Santa Ana field.

The Sacacual sediments are separated from the overlying Mesa formation and the underlying Freites and Oficina formations by distinct unconformities. Relations of the Sacacual group to the older sediments are angular so that it rests variably on Freites or Oficina formation and on markedly different horizons in the Oficina formation. The unconformity between Sacacual and older sediments

[10] H. D. Hedberg, L. C. Sass, and H. J. Funkhouser, *op. cit.*



CARIBBEAN SEA
WEST END OF SERRANIA DEL INTERIOR
CHIMANA GRANDE ISLAND
CHIMANA DEL SUR ISLAND
PUERTO LA CRUZ LOADING TERMINAL CERRO GUARAGUAO
CERRO POZUELOS
CERRO CAMPO ALEGRE
RIO NEVERI
CERRO CATUARO
RIO NARICUAL
CERRO GRANDE
RIO CAPIRICUAL
CERRO BOCA TIGRE
SEA LEVEL
MERECURE
MERECURE
SAN ANTONIO
QUERECUAL
CHIMANA
EL CANTIL
BARRANQUIN
(CARIBBEAN SERIES)
Los Jabillos
CARATAS
VIDOÑO
Naricual
CAPIRICUAL
Los Jabillos
CARATAS
VIDOÑO
SAN ANTONIO
QUERECUAL
CHIMANA
EL CANTIL
BARRANQUIN
GUAYUTA GROUP
MERECURE
SANTA ANITA GROUP
OFICINA OIL FIELD
RIO GUANIPA
OG-5
OG-2
HOLLYWOOD FAULT
OG-122 (PROJ.)
OG-15
OG-7
OFICINA FAULT
OG-112
RIO CARIS
SEA LEVEL
MESA
SACACUAL
FREITES
OFICINA
TEMBLADOR
MESA
SACACUAL
FREITES
OFICINA
IGNEOUS-METAMORPHIC BASEMENT

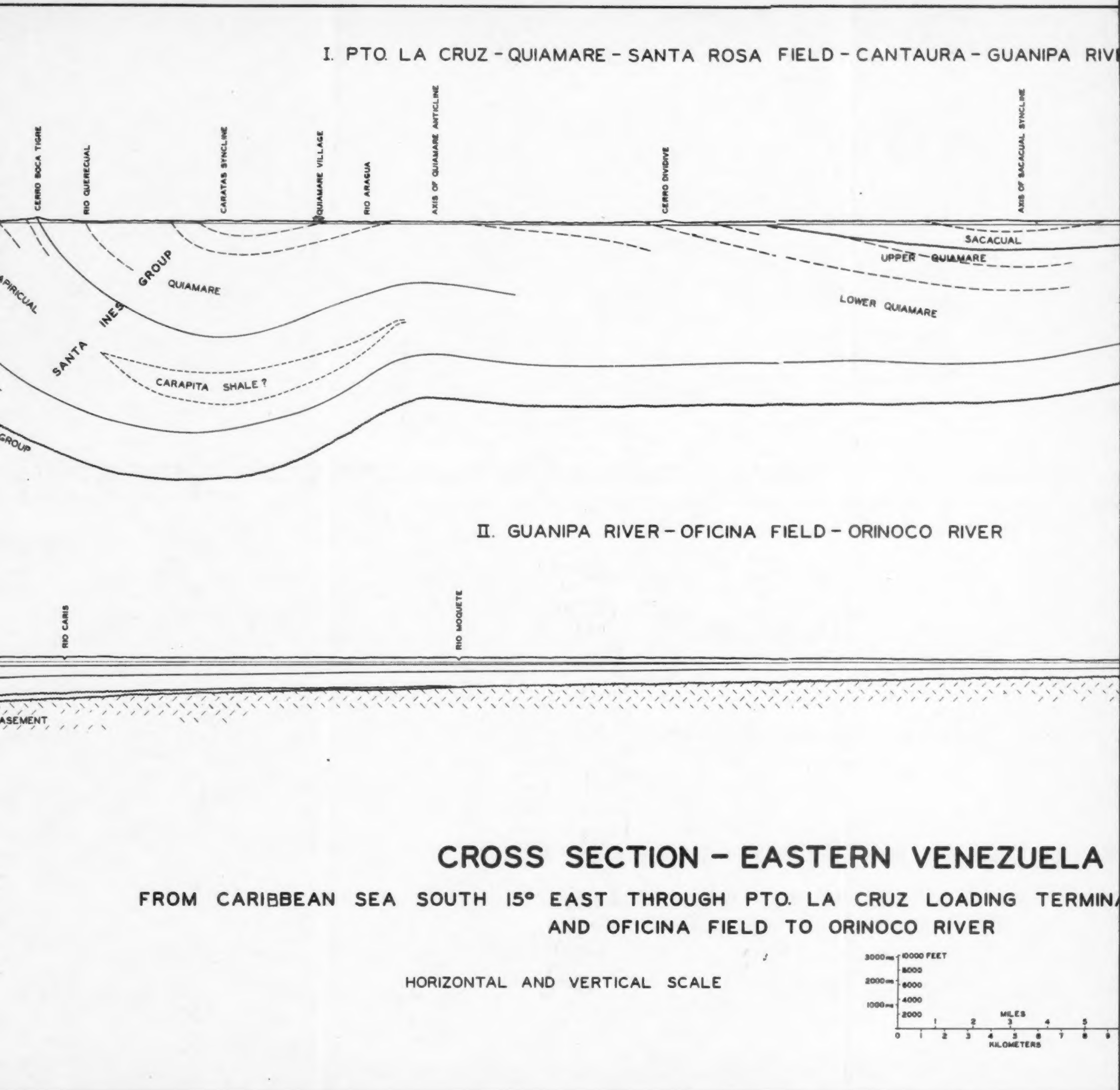
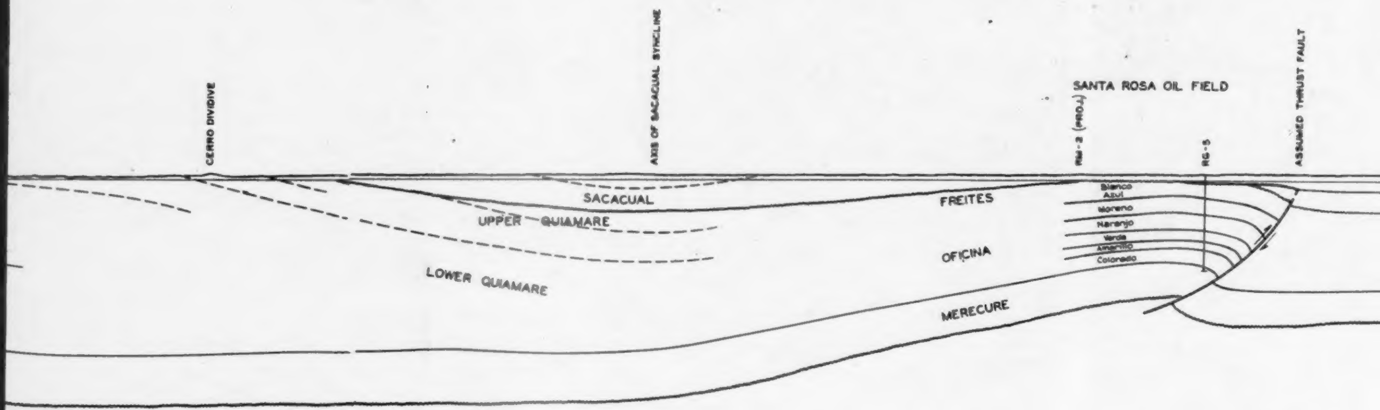


FIG. 3.—Cross section of Eastern Venezuela from Caribbean Sea through Santa Rosa field to Orinoco River.

QUIAMARE - SANTA ROSA FIELD - CANTAURA - GUANIPA RIVER

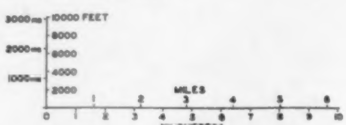


GUANIPA RIVER - OFICINA FIELD - ORINOCO RIVER

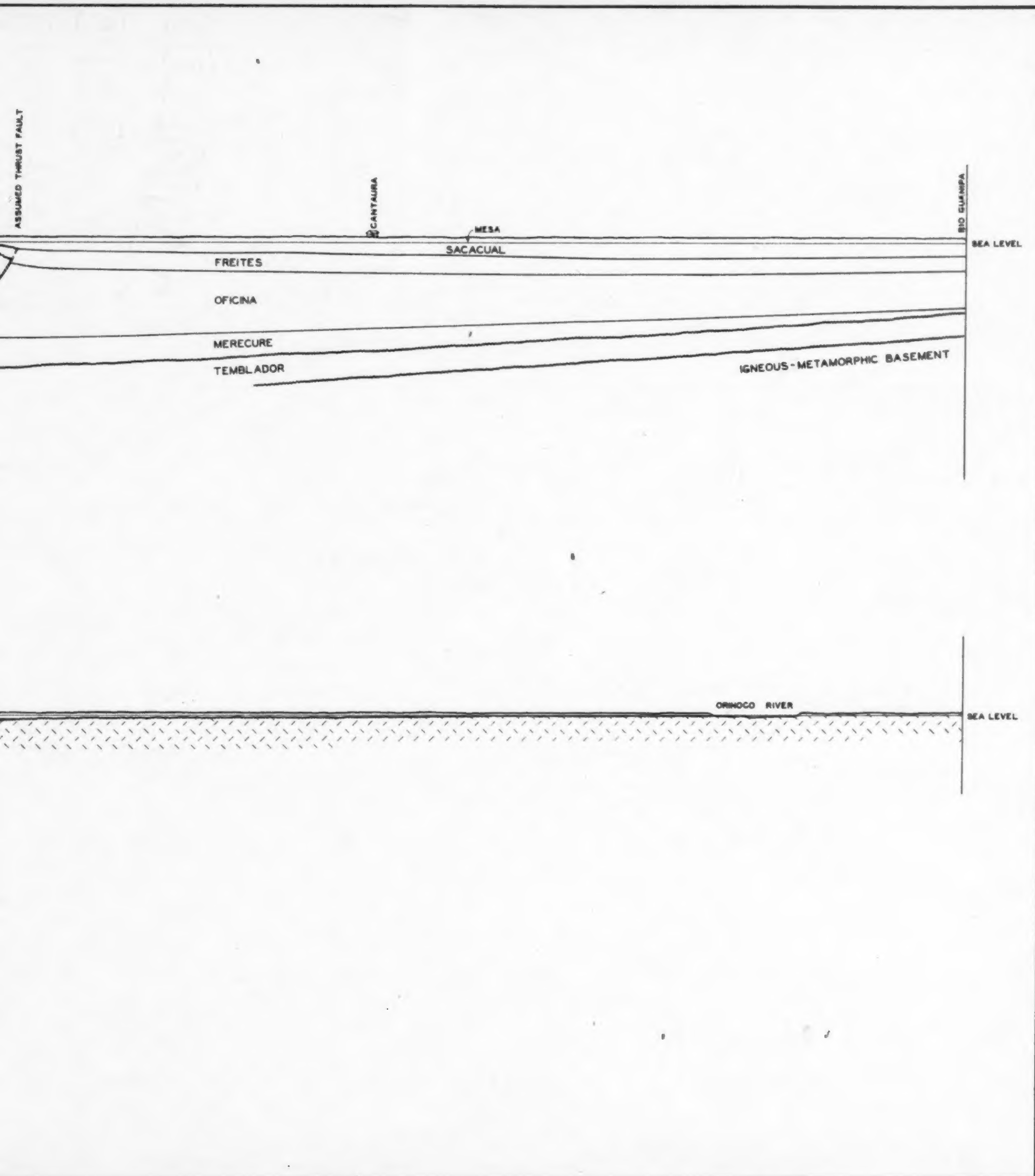
SS SECTION - EASTERN VENEZUELA

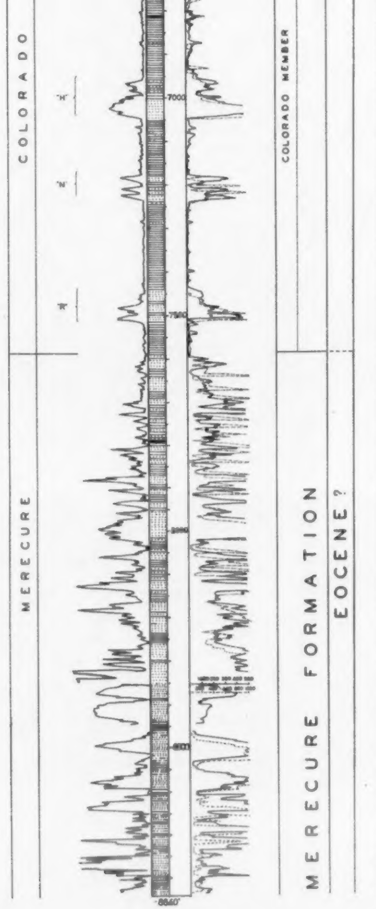
15° EAST THROUGH PTO. LA CRUZ LOADING TERMINAL, SANTA ROSA FIELD AND OFICINA FIELD TO ORINOCO RIVER

L AND VERTICAL SCALE



oss section of Eastern Venezuela from Caribbean Sea through Santa Rosa field to Orinoco River.


ASSUMED THRUST FAULT
CANTAURA
MESA
RIO GUANIPA
SEA LEVEL
SACACUAL
FREITES
OFICINA
MERECURE
TEMBLADOR
IGNEOUS-METAMORPHIC BASEMENT
ORINOCO RIVER
SEA LEVEL



Above log is from AM-2. A summary of tests in this well follows:

Sand	Interval	Daily Rate*	Choke	THP	CHP	Gas Condensate Ratio	Gravity
Colorado C	6600-6620	995	5/8"	2250	2500	15,680	55.9
Colorado D	6650-6660	620	5/8"	2250	2450	13,485	56.8°
Colorado Hu.	6970-6980	596	5/8"	1250	1650	14,665	57.1°
Colorado Hl.	7030-7040	985	5/8"	2025	2200	14,190	49.8°
Colorado N	7179-7185	509	5/8"	1250	1350	16,660	49.3°
Colorado R	7500-7510	596	5/8"	1050	1500	19,000	50.1°
Merecure	7605-7610	210	5/8"	2125	2300	68,971	47.2°
Merecure	8005-8010	232	5/8"	2175	2400	35,000	48.6°
Merecure	8295-8300	112	2-1"	500	1500	170,000	45°
Merecure	8349-8652 Open Hole	131	5/8"	2650	0	112,600	44°

* Barrels Condensate

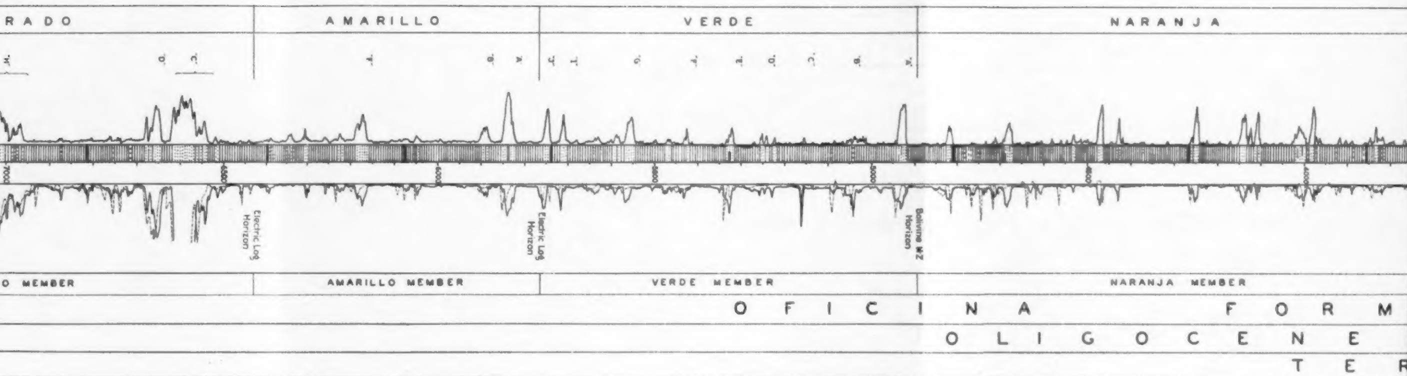


FIG. 4.—Typical columnar section, Santa Ana field. Depths shown in feet.

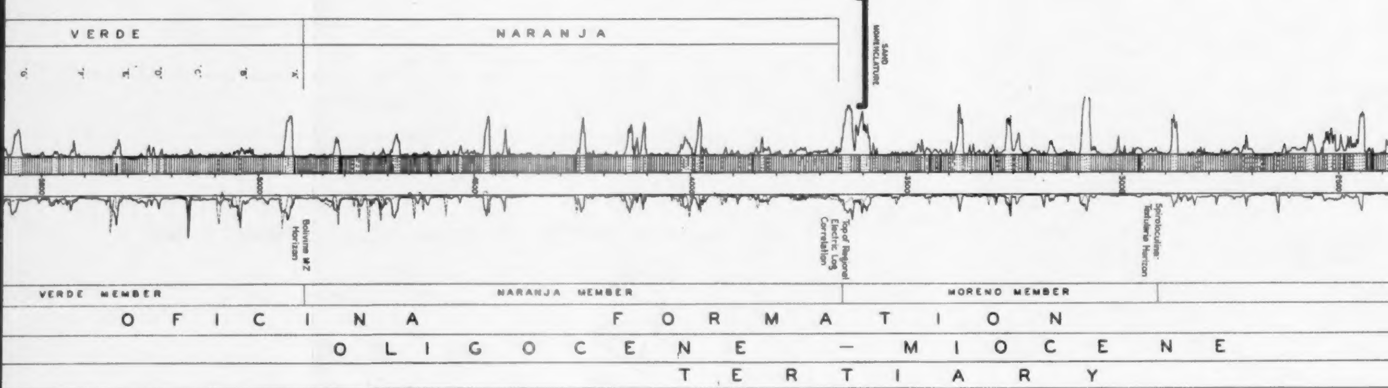
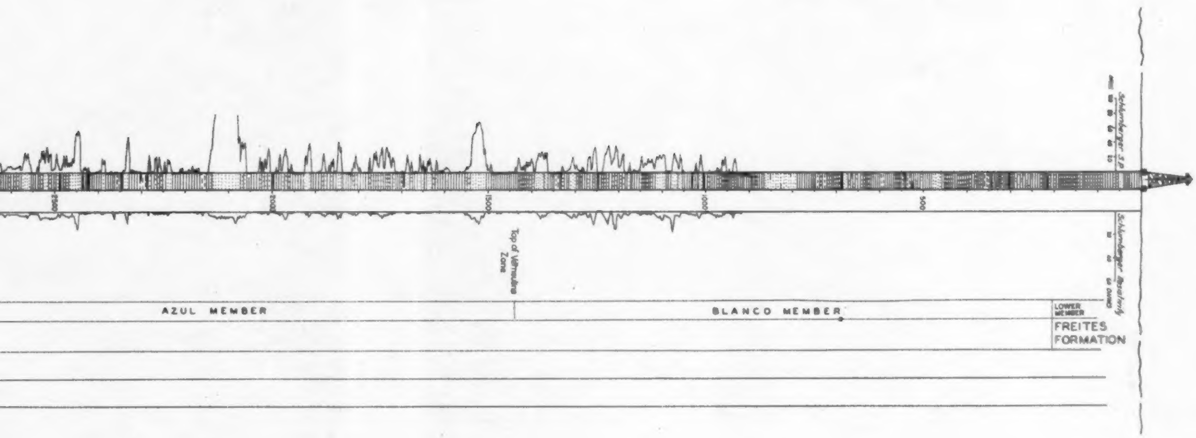


FIG. 4.—Typical columnar section, Santa Ana field. Depths shown in feet.

BULL. AMER. ASSOC. PETROL. GEOL., VOL. 32, No. 10 (October, 1948), Funkhouser et al. Fig. 4



here contrasts with the apparent conformity in the Greater Oficina area. The contact with the Oficina formation in wells in the fields is readily identified by the greater induration of the Oficina sediments, their lithologic characteristics, the presence of marine fossils, mineralogic differences, and by the more persistent electric-log character of the older beds.

The mineralogical character of the Sacacual sediments is variable with the lithologic facies present. The Las Piedras formation contains a complex mineral suite with kyanite, andalusite, staurolite, magnetite, epidote, clinozoisite, garnet, chloritoid, glaucophane, and titanite. The Algarrobo has a much simpler suite lacking glaucophane and titanite, and with epidote, clinozoisite, garnet, and chloritoid either absent or in reduced quantity. The Quiriquire facies is variably simple or complex while the Prespuntal beds show a simple suite commonly lacking the characteristic Las Piedras minerals or possessing them only in very minor amounts.

Marine fossils are lacking in the Sacacual group. *Corbicula* sp. has been found in a few places in the outcropping Sacacual sediments of this area and a persistent horizon of fossil turtles occurs at the base of the Quiriquire formation in the Santa Rosa area. Well samples in this group have yielded no other fossils excepting fish teeth.

The sediments of the Sacacual group here appear to have been deposited under fresh-water conditions (probably lakes and rivers) along the western edge of the brackish-water gulf extending westward into the Eastern Venezuelan basin from the Atlantic at this time. The age of the Sacacual sediments can not be determined closely, but is probably upper Miocene and Pliocene.

The Sacacual sediments are soft and are easily drilled. Correlation of electrical logs is poor. The formation is the source of important fresh-water supplies, particularly in the Santa Rosa area.

FREITES FORMATION

The formation is named from the district of Freites, in Anzoátegui, and the type section is in the Oficina field of that district. Identification of the formation in the vicinity of the Anaco trend is definite and is based on lithology, paleontology, and stratigraphic position. The formation crops out on the Santa Ana and San Joaquín domes and in a broad belt west of the Santa Ana field and extending northward to Aragua de Barcelona. In wells, the Freites formation is known only from the Santa Ana and the north and south San Joaquín domes and from Santa Rosa No. 1. It has been removed from the crestal area of the Guario and Santa Rosa domes by erosion.

The formation probably has a total thickness of 1,500–2,000 feet in the southwestern part of the area. In RG-1 it is about 2,100 feet thick and in outcrops along the Aragua de Barcelona road northwest of the area it is 2,600 feet thick. Because of unconformable overlap of the Sacacual formation only the lower part of the Freites formation is exposed on the Santa Ana and San Joaquin domes. In

the Santa Ana field core drilling has provided good information on the basal 750 feet of the formation. The upper 500 feet of this thickness consists mainly of greenish gray shale and sandy shale with some shaly sandstone. It contains a brackish-water fauna. The lower 250 feet (corresponding with the lower member of the formation in the Oficina field) is dominantly soft greenish gray glauconitic sandstone and very sandy shale with some thin limestones. This lowest section contains an abundant shallow-water marine fauna of mollusks and foraminifera which may be readily correlated with that of the type section.

In RG-1 the formation may be divided into three members as follows.

Upper member.—1,135 feet. Interbedded and interlaminated gray or dark gray shale and greenish gray sandstone. Locally glauconitic. Here and there, beds of chert pebbles. 100 feet of red, brown, and gray mottled claystone at base. No fossils.

Middle member.—565 feet. Gray and greenish gray shale; greenish gray sandstone. Fossiliferous grits at base. Brackish-water foraminifera and alternation of marine and brackish-water mollusks.

Lower member.—530 feet. Fossiliferous grits, black chert conglomerate, sandy limestone, pepper-and-salt sandstone, greenish gray shale. Shallow-water marine mollusks include species of *Chione, Chlamys, Tellina, Corbula, Anomia, et cetera.*

The contact with the underlying Oficina formation in the Santa Ana area is placed at the point of change downward from green and greenish gray glauconitic sediments of shallow-water marine origin to gray and dark gray lignitic sediments of brackish-water origin. The presence of steeper dips in the Oficina formation on the Santa Ana structure and marked variation in the thickness of the upper (Blanco) member of the Oficina formation suggest that a slight angular unconformity may separate it from the Freites formation at least on structural highs.

The Freites formation is overlapped unconformably by the Sacacual group. The contact between the two is based on lithologic differences and on fossil evidence. In areas of structural uplift there is an angular relation between the two and divergence in strike.

On the basis of its fossil content and correlation with the type section, the Freites formation of this area is considered to be upper middle or lower upper Miocene in age.

OFICINA FORMATION

This formation is named from the Oficina field in the district of Freites, Anzoátegui, and the type section is in the wells of that field. Sediments of approximately equivalent age and similar character comprise the principal petroliferous section of all fields on the Anaco trend. Although differing in certain respects from the type section, it has been agreed among the oil companies to use the same formation name for the Anaco area.

The Oficina formation of the Anaco trend includes 7,500–10,000 feet of sediments consisting principally of gray shales, interlaminated shales and sandstone, and light gray fine-grained sandstones. Lignites, thin limestones, and green claystones are minor constituents of fairly common occurrence. For convenience in stratigraphic work, the formation has been divided rather arbitrarily into seven members based on a combination of lithologic, paleontologic, and electric-log characters. These from top to bottom are here briefly described (Figs. 4 and 5).

Blanco member.—Varies from 1,230 to 1,635 feet in thickness on Santa Ana structure. Upper part missing in San Joaquín and Guario fields due to erosion and totally eroded from crestal area of Santa Rosa field. Consists dominantly of gray and dark gray carbonaceous and lignitic shales, interlaminated shale and sandstone, and green claystones, and includes some greenish gray sandstones, thin greenish gray limestones, and lignites. Occupies interval from top of Oficina formation to top of *Verneuilina* zone. *Ervilia* fossil horizon occurs about 400–500 feet above base of member. Variation in thickness in Santa Ana structure suggests unconformity between it and overlying Freites formation on structural highs although no noticeable unconformity elsewhere. Moderately fossiliferous. Fauna consists of brackish- and muddy-water mollusks (*Corbicula, Sphenia, Tagelus, Corbula, Ervilia*) commonly in tough dark gray carbonaceous shales suggesting deposition under swamp or marsh conditions.

Azul member.—Averages 1,450 feet in Santa Ana field, 1,454 feet in JMN-11 (San Joaquín, south), 1,603 feet in JM-19 (San Joaquín, north), 1,748 feet in Guario-5, and about 1,750 feet in the Santa Rosa field. Consists dominantly of interlaminated dark gray silty shale and light gray fine-grained micaceous sandstone, dark gray fissile shale, and light gray fine-grained micaceous shaly sandstone. Also includes thin limestones, greenish and brownish claystones, lignitic shales and streaks of lignite. Occupies interval from top of *Verneuilina* zone to top of *Spiroloculina-Textularia* horizon. Top of *Trochammina M-I* zone occurs about 1,100–1,300 feet below top of member. Characterized by an alternation of marine- and brackish-water fossiliferous beds. Good but rather local electric-log correlation is available in this member.

Moreno member.—About 700 feet thick in Santa Ana field, 1,145 feet in JMN-11 (San Joaquín, south), 1,319 feet in JM-19 (San Joaquín, north), 1,581 feet in Guario-5, and 1,700 feet in the Santa Rosa field. Shows marked northeastward thickening which, between Santa Ana and San Joaquín, is sufficient to suggest mild unconformity. This thickening takes place largely at top of member. Consists predominantly of dark gray fissile shale but includes some thin calcareous sandstones, thin cone-in-cone limestones, lignites, and green claystones. Sediments are laterally variable and electric-log correlations are poor in this member. Occupies interval from top of *Spiroloculina-Textularia* horizon to the highest electric-log horizon of regional extent.

Naranja member.—Averages 1,230 feet in Santa Ana field, 1,309 feet in JMN-11 (San Joaquín, south), 1,439 feet in JM-11 (San Joaquín, north), 1,581 feet in Guario-5, and 1,800 feet in the Santa Rosa field. Consists largely of gray fissile shale and interlaminated shale and sandstone but also includes thin sandstones, lignites, limestones, and claystones. Characterized in lower part on electric logs by sharp resistivity peaks indicating limestones or lignites. Includes section from highest regional electrical-log correlation horizon down to top of *Bolivina M-Z* horizon and contains brackish-water foraminifera and alternations of marine- and brackish-water mollusks. Includes marine upper *Bolivina M-Z* horizon in all fields excepting Santa Ana where this horizon is not present. Electric-log correlations are regionally fair to good in this and all lower members.

Verde member.—Averages 850 feet in Santa Ana field, 890 feet in JMN-11 (San Joaquín, south), 909 feet in JM-19 (San Joaquín, north), 974 feet in Guario-5, and 1,150 feet in the Santa Rosa field. Consists of dark gray shales, interlaminated shale and sandstone, and thin fine- to medium-grained sandstones. Also includes some thin limestones and lignitic shales. Occupies interval from top of *Bolivina M-Z* horizon to an arbitrary point established on the electrical logs of the Santa Ana wells. In general contains a scanty foraminiferal fauna but contains the important *Bolivina M-Z* horizon at the top and the *Liebusella* zone about 400–500 feet below the top. Several *Bolivina M-Z* horizons developed in this member in northern fields. Sands developed on the west in the lower half of member largely pinch out in the central and eastern part of the north San Joaquín dome and are absent in the Guario dome; however, other nearly equivalent sands enter this part of the section in the Santa Rosa field.

Amarillo member.—Averages 650 feet in Santa Ana field, 715 feet in JMN-11, 705 feet in JM-19, 779 feet in Guario-5, and 904 feet in RG-5. Largely dark gray shale and interlaminated shale and sandstone with only a few sands. Includes *Operculinoides* horizon several hundred feet below top of member. Sand development increases in northern fields. Established in Santa Ana field to include dominantly shaly interval between Verde and Colorado sands. Extended to other fields by electric-log correlation.

Colorado member.—Basal member of Oficina formation. Averages 1,100 feet in Santa Ana field, 1,325 feet in JM-11, 1,378 feet in JM-19, 1,414 feet in Guario-5 and 1,574 feet in RG-5 of Santa Rosa field. Contains several light gray fine-grained sandstones and some coarse-grained sandstones, but shale makes up most of total thickness. Includes section from point about 65 feet above highest of several thick sandstones in the Santa Ana field down to top of Merecure formation. Boundaries carried to other fields by electric-log correlation. Fossils scarce and largely confined to few arenaceous brackish-water foraminifera. Colorado P sand resembles underlying Merecure formation in lithologic character.

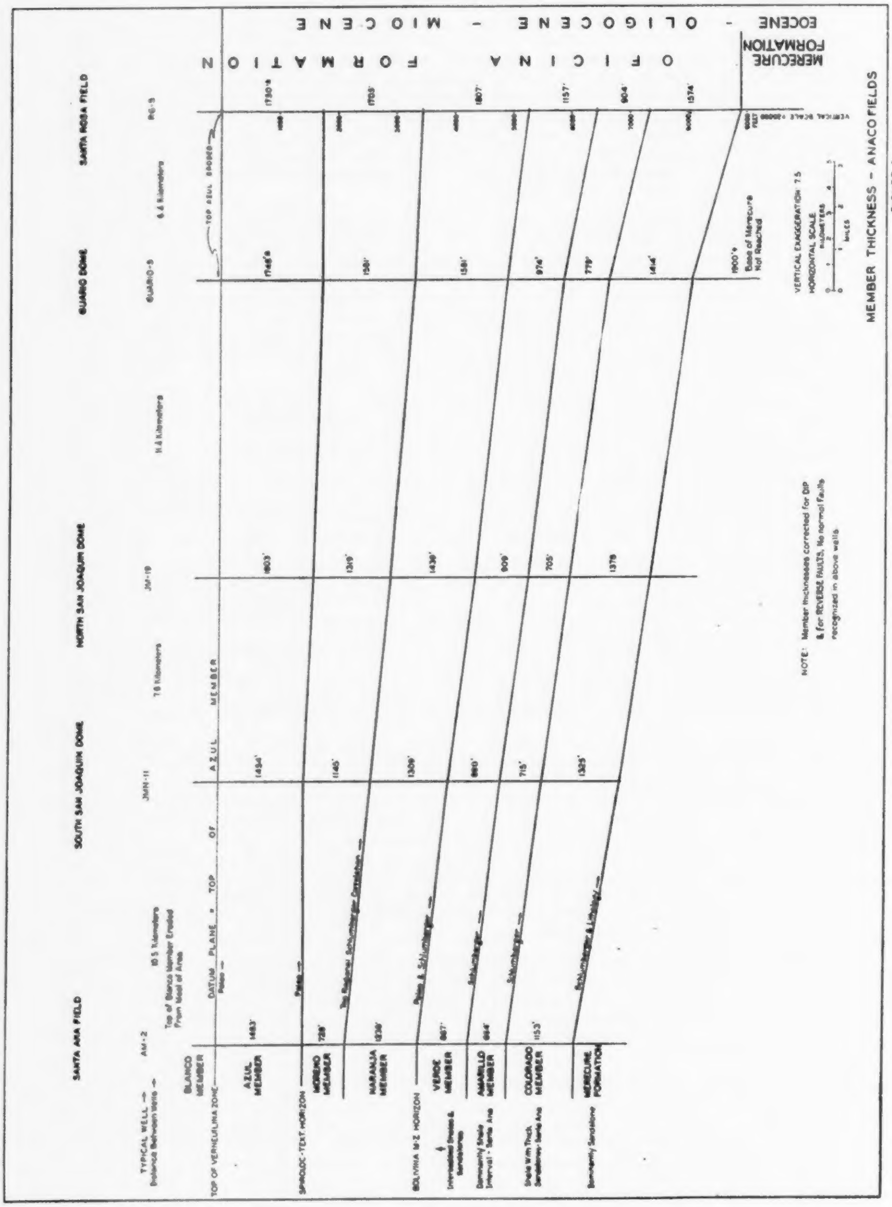


FIG. 5.—Member thickness, Anaco fields.

The Oficina formation of the Anaco fields differs principally from that of the type section in the Oficina field as follows.

1. Greater predominance of shale in Anaco fields
2. Coarse gritty sandstones and glauconitic fossiliferous sandstones are much less common in Anaco fields
3. Somewhat denser, more fissile character of shales in Anaco fields
4. Moderate change in fossil fauna
5. Moderate change in detrital minerals
6. Change in character of contained petroleum

Where overlain by the Freites formation, the top of the Oficina formation is placed at the change from greenish shales and glauconitic sandstones containing shallow-water marine fossils above to gray and dark gray shales and interlaminated shales and sandstones with carbonaceous matter and lignites and a brackish-water fauna below. Where overlain by the Sacacual formation, the contact with the Oficina formation is determined by the characteristic gray shales and interlaminated shales and sandstones of the latter, its greater lithification, the appearance of marine—or brackish-water indigenous foraminifera, the characteristic garnet-chloritoid mineral content of the Oficina sediments, and the appearance of persistent electric-log markers.

The contact of the Oficina formation with the underlying Merecure formation is placed at the top of the nearly continuous sandstone section of the latter formation. Other criteria are the disappearance of the characteristic Oficina formation garnet-chloritoid heavy-mineral suite, increased hardness of drilling, and the disappearance of good electric-log correlation horizons.

The Oficina formation is generally separated from younger formations by unconformities all along the Anaco trend. In contrast to the conformable relations between Oficina and Freites formations in their type area, the Freites near the Anaco axis appears to be slightly unconformable on the Oficina, as indicated by a slight discordance in structure and by marked variations in the thickness of the upper (Blanco) member of the Oficina formation. Where the Oficina formation is in contact with the Sacacual group, a pronounced unconformity intervenes. The superposition of the Sacacual sediments on different beds in the Oficina formation proves a marked angularity at this contact and in the Santa Rosa field a topography of 200–250 feet relief was developed at this surface.

By assuming an average thickness of 1,700 feet for the eroded or partly eroded Blanco member at the top of the Oficina formation, the total thickness of the formation in the different fields is estimated as follows.

Field	*Feet*
Santa Ana field	7,800
San Joaquín (South)	8,500
San Joaquín (North)	9,050
Guario	9,800
Santa Rosa	10,600

The northeastward thickening of the formation as a whole along the Anaco trend is striking. It amounts to about 72 feet per kilometer (120 feet per mile). The direction of maximum thickening appears to be nearly due north. This thick-

ening occurs in all members, although it is somewhat more pronounced in the Moreno member.

Mineralogically, the Oficina formation is characterized by a garnet-chloritoid suite of detrital minerals.

The Oficina formation is moderately fossiliferous from its top down into the upper part of the Amarillo member. Below this point, fossils are scarce and through most of the Colorado member are very rare. The uppermost part of the formation (Blanco member) is rather certainly of brackish-water origin, but the Azul, Moreno, Naranja, Verde, and upper Amarillo members show alternations of marine- and brackish-water forms. The scarcity of fossils in the middle and lower Amarillo and Colorado members may indicate low salinity for the waters in which they were deposited.

Fossils are exceedingly useful for well correlation throughout the area. Among the more important horizons are the following.

Ervilia horizon (within Blanco member)
Top of *Verneuilina* zone (top of Azul member)
Top of *Trochammina M-I* zone (within Azul member)
Spiroloculina-Textularia horizon (top of Moreno member)
Bolivina M-Z horizon (top of Verde member)

The Oficina formation probably includes sediments ranging from middle Oligocene to middle Miocene in age. The molluscan and foraminiferal fauna has not been studied in sufficient detail to allow accurate placing of individual members but the general equivalence of the formation to the Oligocene-Miocene Santa Ines formation outcrops farther north is certain.

Combined faunal and lithologic evidence indicates that the lower part of the formation was probably deposited in water of low salinity. This condition was followed by repeated alternations of marine and brackish-water environments during which most of the formation was laid down. In the final stages of deposition brackish-water conditions predominated. In spite of this variable environment, relative stability is indicated by the persistence of electric-log markers over the whole area throughout all but the upper part of the formation. In general, sediments seem to become thicker and more marine toward the northeast.

The formation is hard and drilling is difficult, as compared with wells in the Greater Oficina area. Hardness increases markedly with depth. Alternation of hard and soft beds in flank areas with moderate to steep dips has resulted in many crooked holes.

MERECURE FORMATION

The predominantly sandstone section encountered below 7,000–7,500 feet in the first Santa Ana wells was at once recognized as a different stratigraphic unit from the overlying Oficina formation. It was first given the name of "Periquito formation." However, with increasing information its equivalence to the Merecure formation of the mountain front area on the north became sufficiently probable so that the unit in the wells is now known by that name although it may be

differentiated as the Periquito member of the Merecure formation. Information on the type section of the Merecure formation has been published.[11]

The Merecure formation of the wells in the fields of the Anaco trend is characterized principally by the abundance of light gray to dark gray, massive to poorly bedded, hard, fine- to coarse-grained sandstones and grits. The continuity of sandstones is broken by laminae and thin beds of hard black carbonaceous shale and intervals of gray claystone and siltstone, but sandstone makes up approximately 50 per cent of the formation. Cross bedding is common. Secondary growth of quartz grains is characteristic.

Similarities to the outcropping formation are the following.

1. Predominance of sandstone as compared with overlying Oligocene-Miocene formations
2. Presence of similar thick coarse-grained quartzose sandstones as contrasted to the more shaly finer-grained sandstones of Santa Ines and Oficina formations
3. Laterally variable character making correlation of individual beds difficult
4. Fresh- to brackish-water environment passing upward into more marine conditions in Santa Ines and Oficina formations
5. Mineralogical similarity
6. Stratigraphic position below Oficina formation, corresponding with stratigraphic position of Merecure below Santa Ines formation

The contact of the formation with the overlying Oficina formation has been subject to considerable discussion, but is generally placed at the top of the dominantly sandstone unit, as indicated by electric-logs (Fig. 4). Unconformity between the Merecure and Oficina formations was originally suggested by the marked lithologic change, the mineralogic change, the greater lithification and silicification of the Merecure sands, and the suggestion of angular relation in the poor correlations afforded by electric logs in the lower part of the Merecure. However, with the contact as drawn at present, correlation in the upper 100 feet of Merecure formation is fairly satisfactory by means of electric logs and parallel horizons in the overlying Oficina formation. It is therefore evident that there is no angular relation unless this contact has been drawn too high.

As the base of the Merecure formation has not been reached in this area, its thickness and relation to older formations here are unknown. The maximum drilled thickness at present is 1,900 feet (Fig. 6).

The formation is in general characterized by a simple mineral suite in contrast to the strong garnet-chloritoid suite of the overlying Oficina formation. However, locally the garnet-chloritoid suite is found to continue down into the Merecure; therefore, this is not an infallible criterion of the formation. Likewise, brookite and anatase are commonly more abundant in the Merecure sandstones than in the Oficina sandstones, but exceptional occurrences are known.

No fossils have been found by the writers in the Merecure formation. An occurrence of "Oligocene" foraminifera has been reported from approximately 1,500 feet below the top of the formation in Guario No. 3, but has not been satisfactorily substantiated.

[11] H. D. Hedberg and A. Pyre, "Stratigraphy of Northeastern Anzoátegui, Venezuela," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28, No. 1 (January, 1944), pp. 1–28; 4 figs., incl. geol. map.

The Merecure formation of the outcrop areas on the north is upper Eocene-lower Oligocene in age.[12] Because of lack of fossils and because it is not known how much of the type section is penetrated by the wells, no more specific age can be assigned to the formation here.

Unstable conditions of sedimentation are indicated for the Merecure formation by the poor quality of electric-log correlations even in adjacent wells. Fresh- to brackish-water environment is indicated by lack of fossils and presence of claystones.

The electric-log character of the formation is particularly outstanding as it is shown on logs as an almost continuous series of peaks. Resistivities are generally high, regardless of oil or gas content, and in spite of the fact that Merecure water is moderately saline; these resistivities are believed to be caused by character of cementation rather than by fluid content.

The formation offers great resistance to drilling. This is due not only to its induration, but also to the abrasive character of the secondary quartz crystals which are generally developed in the sandstones.

CORRELATION

Fortunately for the sake of correlation and stratigraphic work in general, many of the early wells in this area were extensively cored. Among these were RG-1, AM-1, AM-2, JMN-1, and JM-2. Study of these samples provided paleontologic data which made possible nearly accurate correlation throughout the length of the area and with the Oficina field on the southeast. Likewise, heavy-mineral data were of value in identifying the Merecure-Oficina contact and the contact of the Oficina formation with younger beds.

With additional drilling, electrical logs superseded other methods of correlation, first between wells in each field, and then between fields, until now little sampling is done for correlation purposes. After the member names in the Oficina formation were adopted, the principal sand bodies in each member as shown on the electric logs were named by letters in order from top to bottom (Verde A, B, C, *et cetera*, Colorado A, B, C, *et cetera*). These sands in their characteristic manifestations on the electric logs have now become the principal bases for correlation. They are supplemented by lignite or limestone resistivity peaks which locally constitute satisfactory markers.

The original subdivision of the thick Oficina formation into the more easily recognized members was initiated in the Santa Ana field by Mene Grande geologists in 1939 and was subsequently adopted by the Creole, Socony, and Texas companies. Expansions and corrections have been freely discussed among the operating companies so that essentially the same nomenclature is now used by all concerned.

Correlation within the extremely variable Merecure formation was for a long time unsuccessful, either by electric-log characters or by any other means, but

[12] Hedberg and Pyre, *op. cit.*

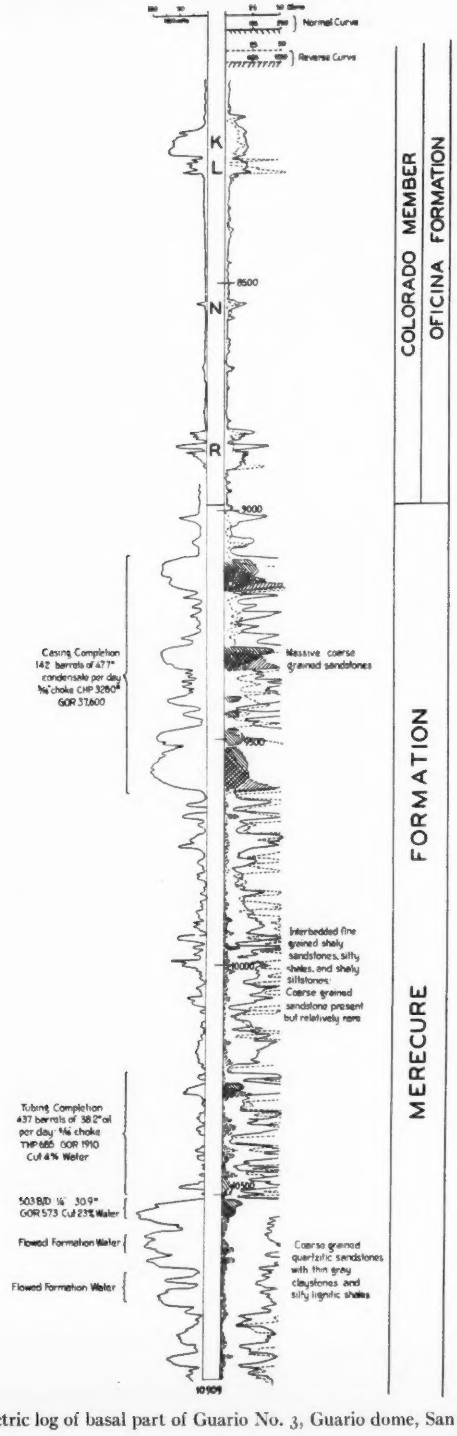


FIG. 6.—Electric log of basal part of Guario No. 3, Guario dome, San Joaquín field.

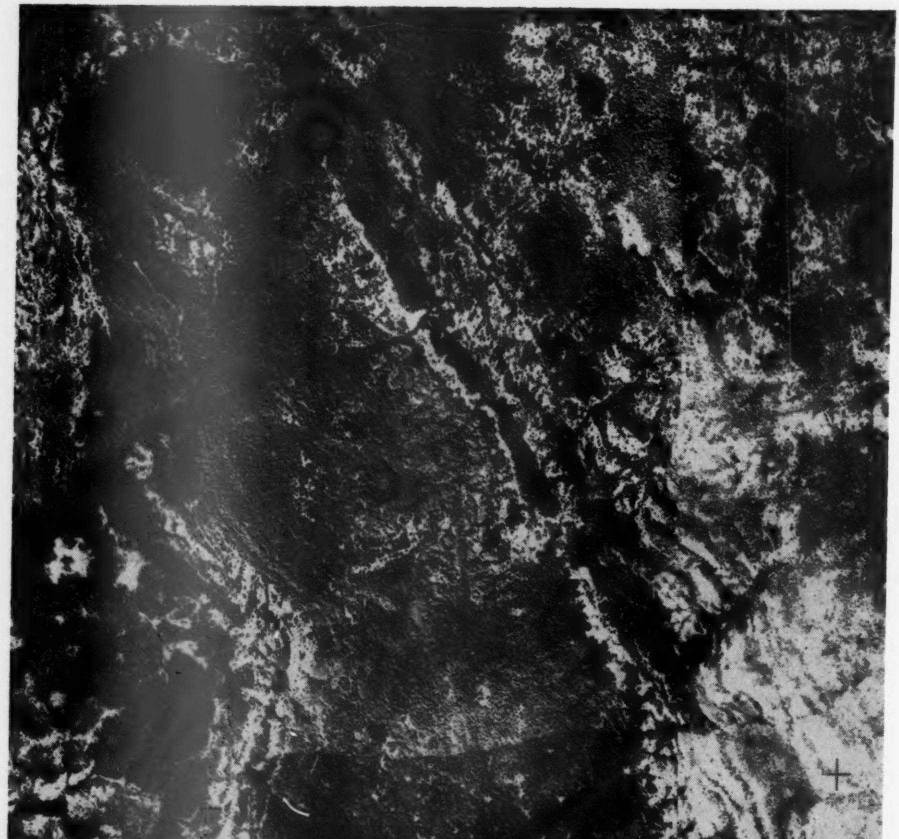


FIG. 7.—Aerial photograph of Santa Ana structure. Scale, 1:50,000.

in the Guario dome sufficient evidence has become available to allow the Socony to establish a system of letters for Merecure sands.

STRUCTURE

GENERAL

The northeast-southwest Anaco line of structure stands out as a distinctly anomalous feature, cutting obliquely across the general trend of the Eastern Venezuela basin. Superficially it consists of a series of elongate domes slightly *en échelon* but in general aligned. These domes are without exception asymmetrical, with the steep flank toward the southeast indicating pressure from the northwest. Seismograph work and drilling have now established that the southeastern flank of the Santa Ana structure is actually overthrust toward the southeast and wells JMN-7 and JM-8 have suggested a similar condition for the San Joaquín domes. Further work will also probably show overthrusting of the Guario and Santa Rosa domes toward the southeast. The similarity of all of these individual structures seems to call for a common origin.

Excepting for the probable line of thrusting along the southeast side of the whole chain of domes, there is very little faulting known in the Anaco fields—remarkably little when compared with the intricate system of faults in the Greater Oficina fields on the southeast. In the Santa Rosa field, however, three reverse faults have been found. Their trend is uncertain, but the presence of horizontal slickensides and the limitations imposed on their position by unfaulted wells suggest that they are strike-slip faults with trends northwest-southeast parallel with the direction from which the general thrusting and folding pressure was applied. In may be conjectured that there are similar strike-slip faults in the saddle areas between individual domes where no drilling has been done and that they are the cause of offsets in the alignment of the domes.

The surface distribution of formations along the Anaco trend suggests that the structure plunges northeastward along the axis since the northeastern domes (Santa Rosa and Guario) are covered with young Sacacual beds, whereas Oficina and Freites formations are exposed on the San Joaquín and Santa Ana domes. This effect is only superficial, however, and is due to gentle eastward tilting of the area in post-Sacacual time. Actually, where the unconformable Sacacual cover is removed the plunge of the Anaco trend is seen to be toward the southwest since increasingly younger parts of the Oficina formation are exposed in this direction. On the other hand, the northward thickening of the Oficina formation more than neutralizes this plunge with depth, so that the top of the Merecure formation is found increasingly farther below sea-level from southwest to northeast.

The origin of the Anaco trend of uplift is not yet clear. Its isolation, distance from areas of deformation, and the lack of adjacent parallel features make the problem especially difficult. In the Santa Ana area the seismograph has indicated that the northwest-dipping thrust-fault plane flattens with depth and merges with bedding planes and that the Santa Ana domes are merely the result of superficial wrinkling above the thrust plane below which strata are essentially hori-

zontal. The idea has therefore been suggested that the deformative pressure was the result of the mountain-making forces on the north or northwest which were transmitted southward through the very competent Merecure formation and that the faulting was localized in the Santa Ana area by the southward thinning of the Merecure formation, which rendered it incompetent to transmit the force beyond this point without rupturing. This relation of the thrusting to the thinning of the Merecure formation might seem plausible if only the Santa Ana structure were to be considered but does not satisfactorily explain the northeastward trend of the uplift in the direction of Santa Rosa.

However, the lithification and silicification of the Merecure formation and the abnormally high temperature along the whole Anaco trend suggest the possible relation of this line of structure to a deep-seated disturbance in the basement rocks. This is also supported by the pronounced magnetic manifestation of the line of structure as shown by magnetometer work.

Carbon ratios of coals in the Oficina sediments indicate little metamorphism of this formation. Two coal samples from the Colorado member of the AM-1 well from depths between 6,350 and 6,450 feet show 46 and 47 per cent fixed carbon.

Structural features (some of which are only estimates because of the few wells drilled) of the several domes along the Anaco trend below the cover of Sacacual sediments are compared in Table III.

TABLE III

COMPARISON OF STRUCTURAL FEATURES

	Santa Ana		*San Joaquín*		*Guario*	*Santa Rosa*
	West	*East*	*South*	*North*		
Strike of axis	N. 65° E.	N. 65° E.	N. 50° E.	N. 60° E.	N. 60° E.	N. 45° E.
Oldest beds at surface or below Sacacual blanket	Blanco	Freites	Blanco	Blanco	Blanco	Azul
Elevation of crest (feet)						
Top of Moreno	−2,000	−1,950	−1,850	−1,150	−1,000	− 900
Top of Verde	−3,950	−4,000	−4,300	−3,900	−3,950	−4,350
Top of Merecure	−6,400	−6,700	−7,200	−6,900	−7,100	−8,000
Minimum length of closed area Top of Verde (kilometers)	4	4	5.5	5	10	8
Minimum breadth of closed area Top of Verde (kilometers)	3.5	3	3.5	4	5	6
Minimum area of closure (acres) Top of Verde	3,000	2,700	3,600	4,500	8,000	8,000
Minimum amount of closure (feet) Top of Verde	750	1,200	1,000	1,600	1,700	1,500

Note.—In these statistics all domes are assumed to be separated by faulting through the saddle or synclinal area between domes. This is open to question especially in the case of the North San Joaquín and Guario domes.

SANTA ANA STRUCTURE

The Santa Ana structure is an asymmetrical anticline trending N. 65° E. and showing three local domes at the surface and at shallow depth, but with only two domes at greater depth. The westernmost dome is structurally highest, as indicated by the Oficina outcrop, and the two eastern domes apparently merge into one at depth. The gentle flank is on the northwest and shows dips of 3°–12°. The steeper flank is southeast and shows dips of 20°–27°. This flank is also marked by a major northwest-dipping thrust plane indicated by seismograph work and confirmed by repetition of section in the Colorado member of Rincón No. 1 (210 feet) and Rincón No. 3 (590 feet). The thrust fault apparently parallels the trend of the anticlinal axis. Seismograph work, as well as petroleum accumulation, indicates that subsidiary transverse faulting also crosses the structure. It also suggests that strata below the major thrust plane are nearly flat and that the anticline is the result of drag on the upper side of the thrust; flat core dips below the thrust in Rincón No. 1 confirm the dip shown by the seismograph. A persistent thinning of the Rincón No. 1 and No. 2 well sections in spite of high dips on the southeast flank suggests that this flank contains a great many normal faults which are very small individually but which are highly important collectively; miniature normal faults in cores support this possibility. Following the thrusting which formed these domes, it seems probable that the crest slumped and that the southeast flank adjusted itself during this period of relaxation by the development of a series of small gravity faults which probably dip northwest (crestward).

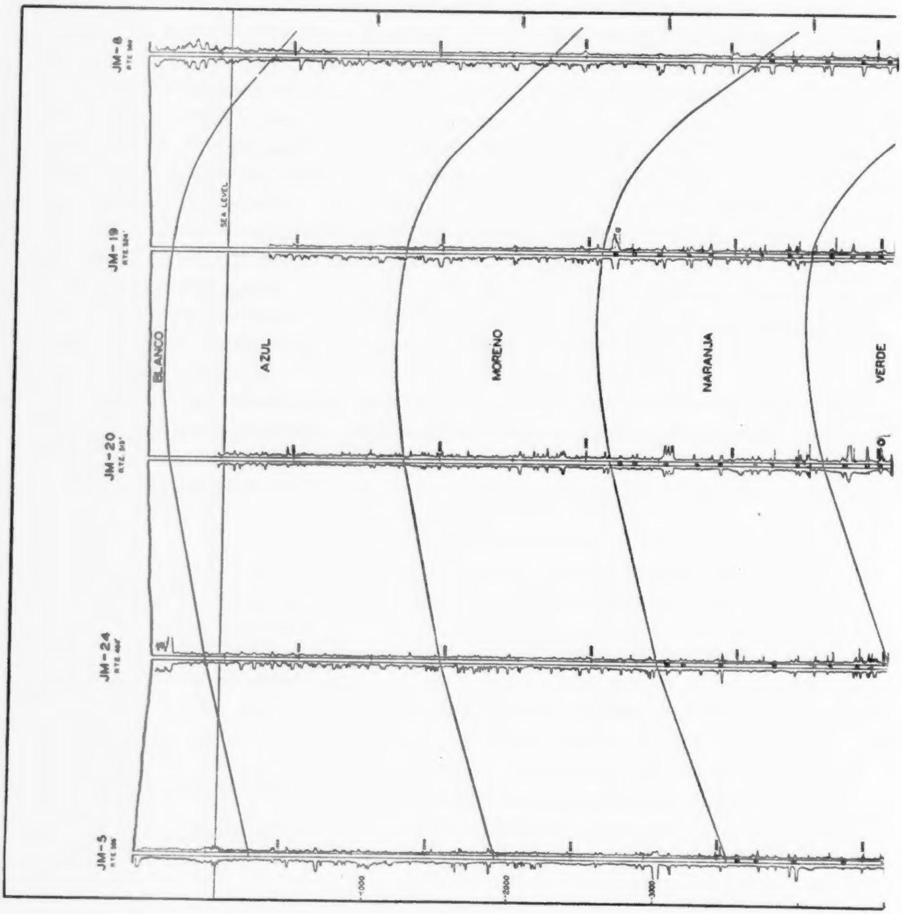
SAN JOAQUÍN FIELD

The south dome of the San Joaquín field has an axial trend of N. 50° E. as compared with the trend of N. 60° E. of the north dome and the Guario dome. All three domes are asymmetrical. The northwest flanks have dips locally as steep as 25° and the southeast flanks have dips as steep as 80° (JMN-7, JM-8, and Guario No. 2). The Oficina formation crops out at the crest of the north and south domes, but is overlapped by the Sacacual on the Guario dome.

Thrust faulting is almost certainly present in the lower part of JM-8 where dips suddenly change from about 70° to essentially flat (Fig. 8). The amount of displacement has not been ascertained because of lack of correlation in the flat beds. The very long section in JMN-7 indicates high dips, but lack of cores and lack of definite correlation in the bottom part of the hole makes it impossible to localize the suspected thrust fault. Guario No. 2 is apparently not faulted but the persistent 50° dip undoubtedly indicates proximity to the controlling thrust.

Minor normal faults with displacements of as much as 150 feet have been encountered in JM-24, Guario No. 4, 6, 7, and 9, but dips and strikes have not been definitely ascertained. Delineation of small faults such as these is of course difficult in steeply dipping beds.

A deep saddle is present between the south and north San Joaquín domes, and numerous discrepancies in accumulation and oil-zone thicknesses indicate that


JM-8
JM-19
JM-20
JM-24
JM-3
SEA LEVEL
BLANCO
AZUL
MORENO
NARANJA
VERDE
-1000
-2000
-3000

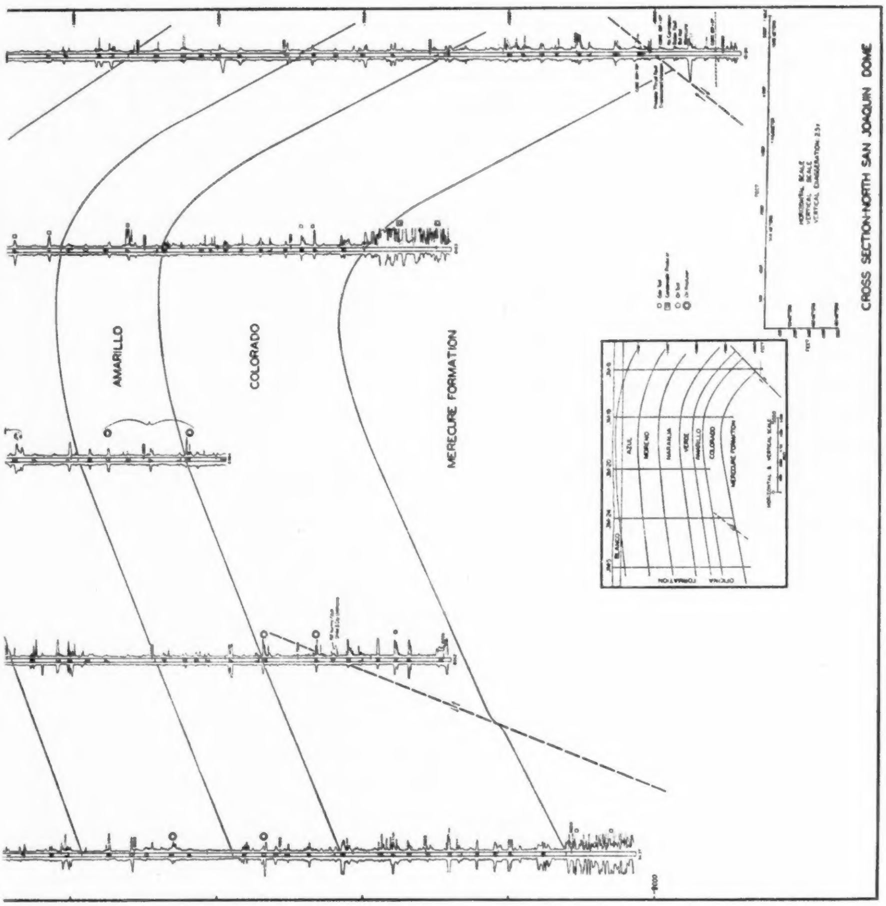


FIG. 8.—Cross section, North San Joaquín dome.

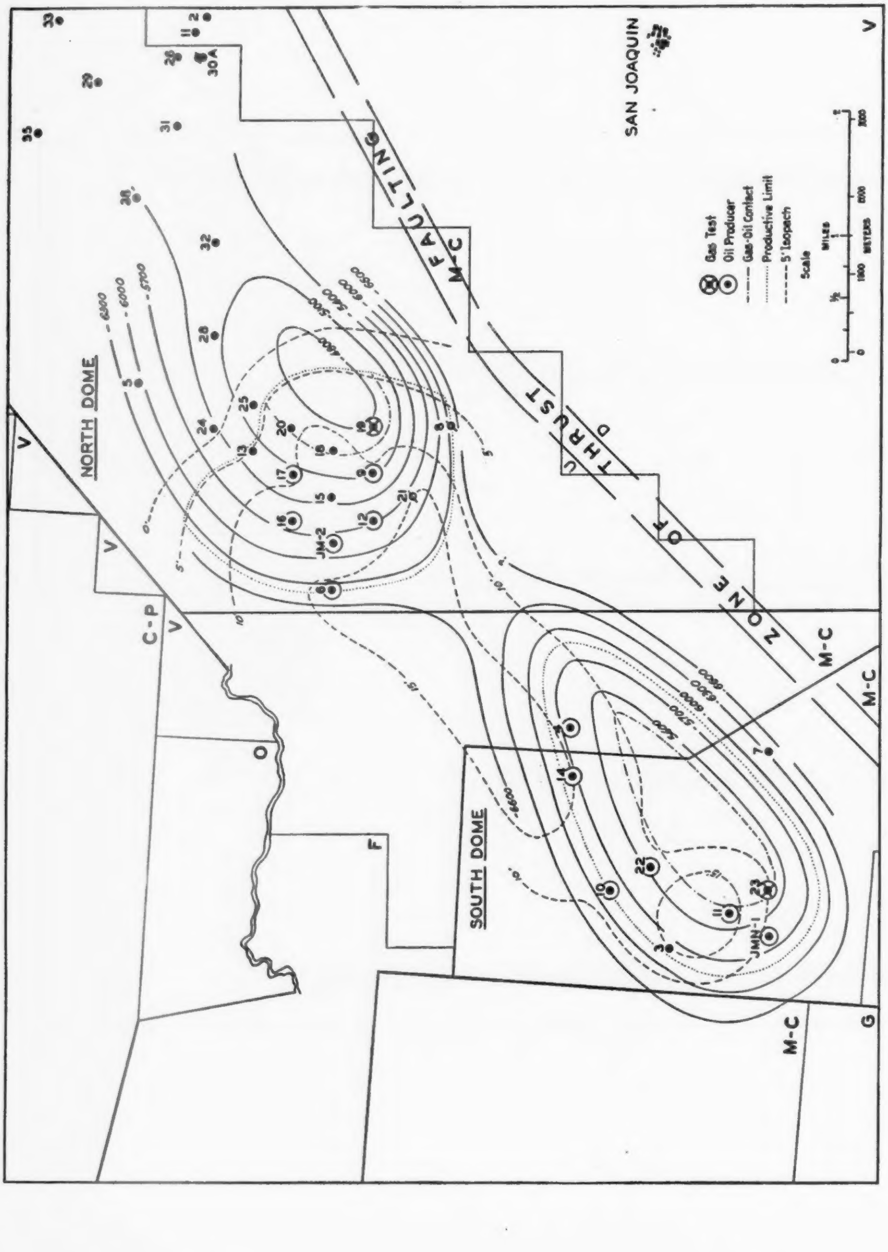


FIG. 9.—Contour and isopach map of Verde I sand, San Joaquín field.

these two domes are definitely separated either by the saddle or by saddle faulting. The saddle between the north San Joaquín dome and the Guario dome is not very pronounced and these two domes may contain common reservoirs, sand developments permitting.

A long flat saddle separates the Guario dome and the Santa Rosa field, and there is some possibility that at least one small area of doming is developed within this saddle in the vicinity of Guario No. 5. It seems most probable that at least Merecure production will be found to extend across the saddle between the north and south San Joaquín domes and between the Guario dome and the Santa Rosa field.

Figures 9 and 10 include structure-isopach maps of the Verde I and Colorado A sands. These two sands are the largest producers in the Anaco fields, having produced 4,200,000 and 5,600,000 barrels, respectively.

SANTA ROSA FIELD

The Santa Rosa dome strikes N. 45° E. It is an asymmetrical feature with a gentle northwest flank and a steep and probably faulted southeast flank. The structure shows little if any reflection in the surface Sacacual sediments which cover it completely, and it is evident that the major folding was completed before Sacacual time. Wells go directly from Sacacual sediments into the Azul member of the Oficina formation, indicating that 2,400–3,700 feet of Freites and Oficina formation had been removed prior to Sacacual deposition.

Although the probable thrust fault forming the southeast flank of the dome has not yet been encountered by any wells, three reverse faults have been found. One at 5,070 feet in the Naranja member in RG-2 has a displacement of 150 feet. RG-5 is cut by two faults, one at 3,185 feet in the Moreno member has a displacement of 130 feet, and the other at 9,550 feet in the Colorado member, has a displacement of 140 feet. These are all different faults and are probably steeply dipping strike-slip faults aligned at right angles to the elongation of the dome. They are evidenced on amazingly clear repetitions of the electric-log sections and are accompanied by abrupt increases in core dips adjacent to the fault planes. Cores in RG-2 showed horizontal slickensiding. In one well a caliper survey shows a nearly perfect repetition of minute differences in hole size through the first and second occurrences of the same section.

The upper part of RG-6 is cut by a small normal fault (±70 feet), but this type of faulting has not been identified in the other well sections.

The structural complexities shown by the few wells in the Santa Rosa field indicate that this dome had a structural history somewhat more severe than that of the relatively simple domes on the southwest. This, with the greater amount of pre-Sacacual erosion, suggests that the controlling thrust increases in displacement from southwest to northeast, though it could mean the opposite, with numerous small faults relieving the pressure largely taken care of by one large fault in other areas.

FIG. 9.—Contour and isopach map of Verde I sand, San Joaquín field.

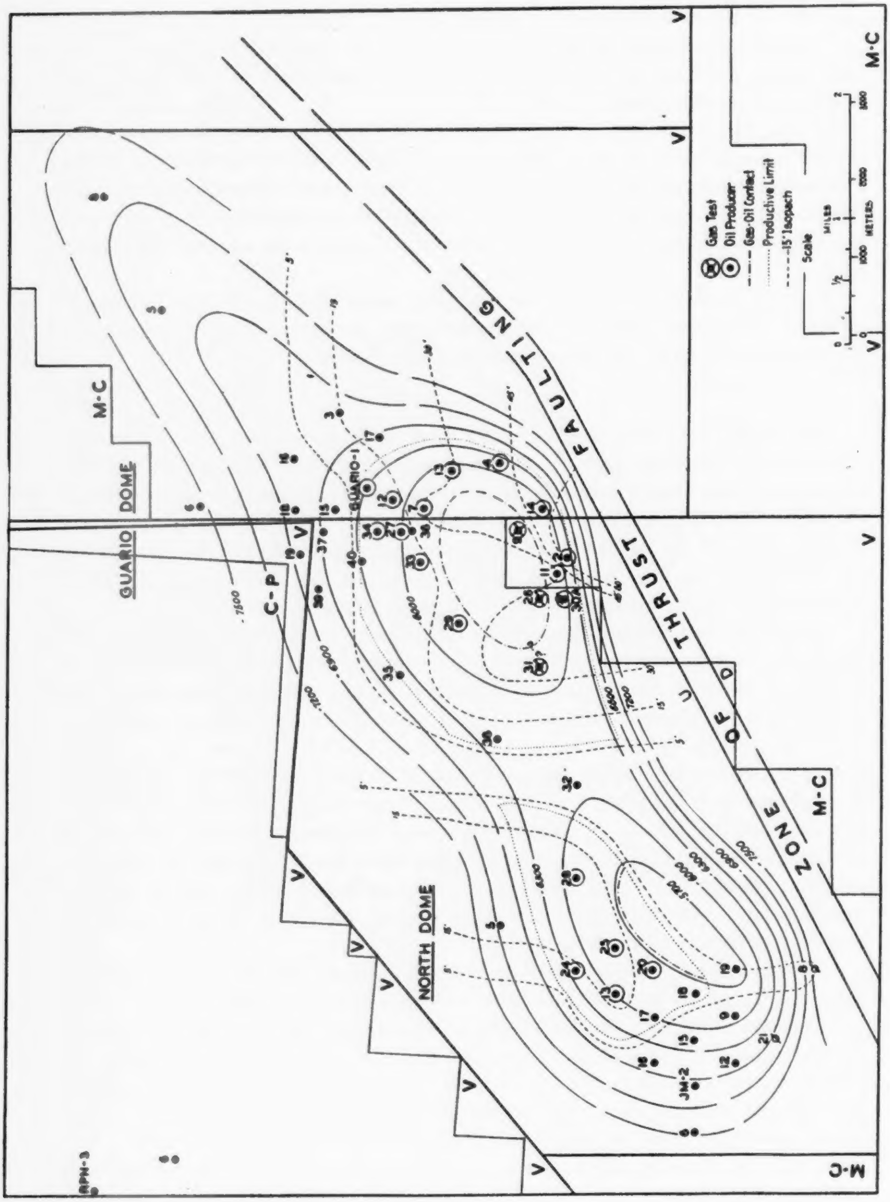


FIG. 10.—Contour and isopach map of Colorado A sand, San Joaquín field.

GEOLOGIC HISTORY

The earliest event evidenced by the known geologic section of the Anaco area was the deposition of the upper part of the Merecure formation. Paleontological data from the outcrop area of this formation in northeastern Anzoátegui definitely indicate that deposition of this formation there began in upper Eocene time.[13] However, this deposition probably continued into Oligocene time as there appears to be no break between the non-fossiliferous upper part of this thick formation and the overlying Santa Ines formation which is Oligocene-Miocene in age.

As there are almost no fossils in the Merecure formation of the Anaco trend, as it is 90 kilometers south of the nearest outcrop of the Merecure formation, and as the base of the formation has not been reached in the wells, it is not certain how much of the type Merecure is represented or how much, if any, of the drilled section is upper Eocene and how much lower Oligocene. It is even possible that much of the upper Merecure of the well sections is the time equivalent of the basal Santa Ines sandstones of the mountain-front section.

Whatever the exact equivalent, the thick, fine- to coarse-grained, laterally variable sandstones of the Anaco Merecure, interspersed with claystone intervals and barren of fossils, appear to have been deposited under dominantly fresh-water or at least non-marine conditions. The high-angle cross bedding commonly noted in these sandstones and their lateral variability suggest that they may in large part have been deposited by streams and their clean quartzose character is suggestive of derivation from the Guayana shield area on the south, rather than from the mobile borderland on the north.[14] The Anaco area was probably near the south border of the rapidly subsiding Eastern Venezuela geosyncline, and the dominantly sandstone section here may be the time equivalent of the coal-basin deposits of the Naricual area farther north, which were near the center of the axis of subsidence. There is a possibility that a part of the Merecure is equivalent to the basal Oficina "U" sands of the Greater Oficina area, but again lack of fossils hampers exact correlation.

With the beginning of Oficina (Santa Ines) time, uplift of the northern borderland became more pronounced while at the same time subsidence of the southward-shifting axis of the geosyncline was accentuated. Rivers and swamps in the Anaco area were replaced by more extensive bodies of water in which the more laterally persistent strata of the basal Oficina (Colorado member) were deposited. In early Oficina time these waters were of low salinity and the Colorado member appears to have been deposited in the inner fresh- to brackish-water part of a gulf which extended into Eastern Venezuela from the east. The character of sediments had changed markedly both with respect to lithology and mineralogy from that of the Merecure formation and this was probably not only the result of a different

[13] Hedberg and Pyre, *op. cit.*

[14] Hedberg and Pyre, *op. cit.*

FIG. 10.—Contour and isopach map of Colorado A sand, San Joaquín field.

depositional environment, but also due to replacement of the Guayana shield as a source by the rising mountains of the northern borderland, which contributed an increasingly large share of the geosynclinal fill as they rose relative to the sinking of the geosyncline.

As the basin deepened in keeping with more rapid subsidence, the eastern sea began to invade the area and the alternating marine- and brackish-water deposits of the Amarillo, Verde, and younger members of the Oficina formation replaced the brackish- and fresh-water deposits of the lower part of the formation. For a long period, in late Oligocene and early Miocene time, the area was near critical level as indicated by alternations of marine- and brackish-water shales and thin sandstones, lignites, and claystones. Subsidence was closely compensated by deposition, and crustal conditions were in general very uniform although there was enough local differential to develop disconformities, such as may be represented by the thickness variation of the Moreno member. The area was still south of the main axis of subsidence, as indicated by the northward thickening of all units toward the axial area of maximum deposition and toward the source of the sediments.

Toward the close of Oficina time, the rate of subsidence diminished and the influence of the eastern sea decreased with the result that the Moreno member was deposited largely under brackish-water and swamp conditions. The initial preliminary uplift of the Anaco axis began so that when dominant marine conditions returned in middle Miocene time the Freites formation was deposited with mild unconformity on the Oficina formation across the crest of the structural trend, although there was probably no break in deposition on either flank.

Lower Freites sedimentation represented a more sustained and extensive marine incursion than had previously taken place in the history of the known sediments of the area. Southward migration of the geosyncline had brought its axis near the Anaco area and the sea extended far westward beyond these fields. While shallow-water conditions still prevailed, the swampy shore common to Oficina time was far removed and the Freites formation was deposited in clearer water. The lignites, claystones, and swamp deposits of the Oficina formation are lacking in the Freites, and greenish glauconitic sandstones and shales replace the gray carbonaceous sediments of the Oficina formation.

Throughout the later course of Freites deposition the water of the Eastern Venezuela gulf began to grow more brackish as evidenced by the gradual change in character of the fossil fauna. Approach to near-shore conditions and increased influx of sediment from the northern borderland are indicated by the entrance of sands and even thin conglomerates in the upper Freites of the northern area while marine fossils disappear from here on in the record.

In upper Miocene time there occurred one of the major crustal disturbances in the history of the region. Pronounced folding and uplift took place along the northern edge of the Eastern Venezuela geosyncline. The axis of the basin of deposition shifted southward to the latitude of the Santa Ana field and there was a

general replacement of the Freites sea by brackish to fresh waters forming the inland end of a gulf opening into the ocean on the east. Along the axial part of this gulf, there was no break in deposition at the end of Freites time—only a gradual transition to increasingly sandy and less marine sediments of the overlying Sacacual group. However, farther north and nearer the mobile border of the geosyncline, there was a broad belt of emergence throughout which the Freites and Oficina sediments (or their northern equivalents, the Santa Ines formation) were eroded before fresh-water sediments of the Sacacual group were unconformably deposited upon them.

During the orogeny at the end of Freites time, strong local uplift by faulting and folding occurred all along the narrow Anaco trend, cutting obliquely across the basin. The most pronounced uplift occurred at the northern end of the trend where 2,400–3,700 feet of sediments were removed from the Santa Rosa dome so that the succeeding Sacacual deposits rest with profound unconformity on various horizons of the upper Oficina formation. However, uplift and erosion occurred all along the trend and it is probable that successively younger Sacacual deposits overlapped each other on the flanks of this line of uplift during the succeeding cycle of deposition until they finally spread completely over its axis.

Sacacual fresh-water deposition in the Anaco area probably continued until the middle of Pliocene time when the whole Eastern Venezuela region was uplifted and tilted toward the east. The effect of this tilting and subsequent erosion is seen along the Anaco trend in the fact that large areas of the westernmost structures (Santa Ana and San Joaquín) have been stripped clean of Sacacual sediments, whereas the Sacacual still covers the Santa Rosa and Guario domes. In Pleistocene time streams flowing southward from the recently uplifted mountains on the north spread the alluvial deposits of the Mesa formation across the whole area, probably to a thickness of 200–300 feet. With further eastward regional tilting and the dominance of erosion over deposition, the Mesa formation has now been almost entirely removed from the Anaco area (excepting a small remnant near the Anaco pump station). The westward-facing mesa front is already 10–20 kilometers east of the Anaco fields and present erosion is steadily driving this escarpment farther east.

OIL AND GAS RESERVOIRS

The estimated productive surface area of the Anaco fields described herein is 28,865 acres. Sand bodies containing oil or gas have been found throughout the 11,000 feet of presently explored section. A seismograph shot hole bottomed in the Sacacual formation on the Guario dome had a gas blow-out. Several wells have had gas blow-outs from sands in the Blanco and Azul members of the Oficina formation; 1 sand has tested gas in the Moreno member; 5 oil sands and 7 gas sands have been tested in the Naranja member; all 9 productive sands in the Verde member have yielded oil completions; 5 oil sands and 1 gas sand have been tested in the Amarillo member; and 9 oil sands and 2 gas sands have been tested

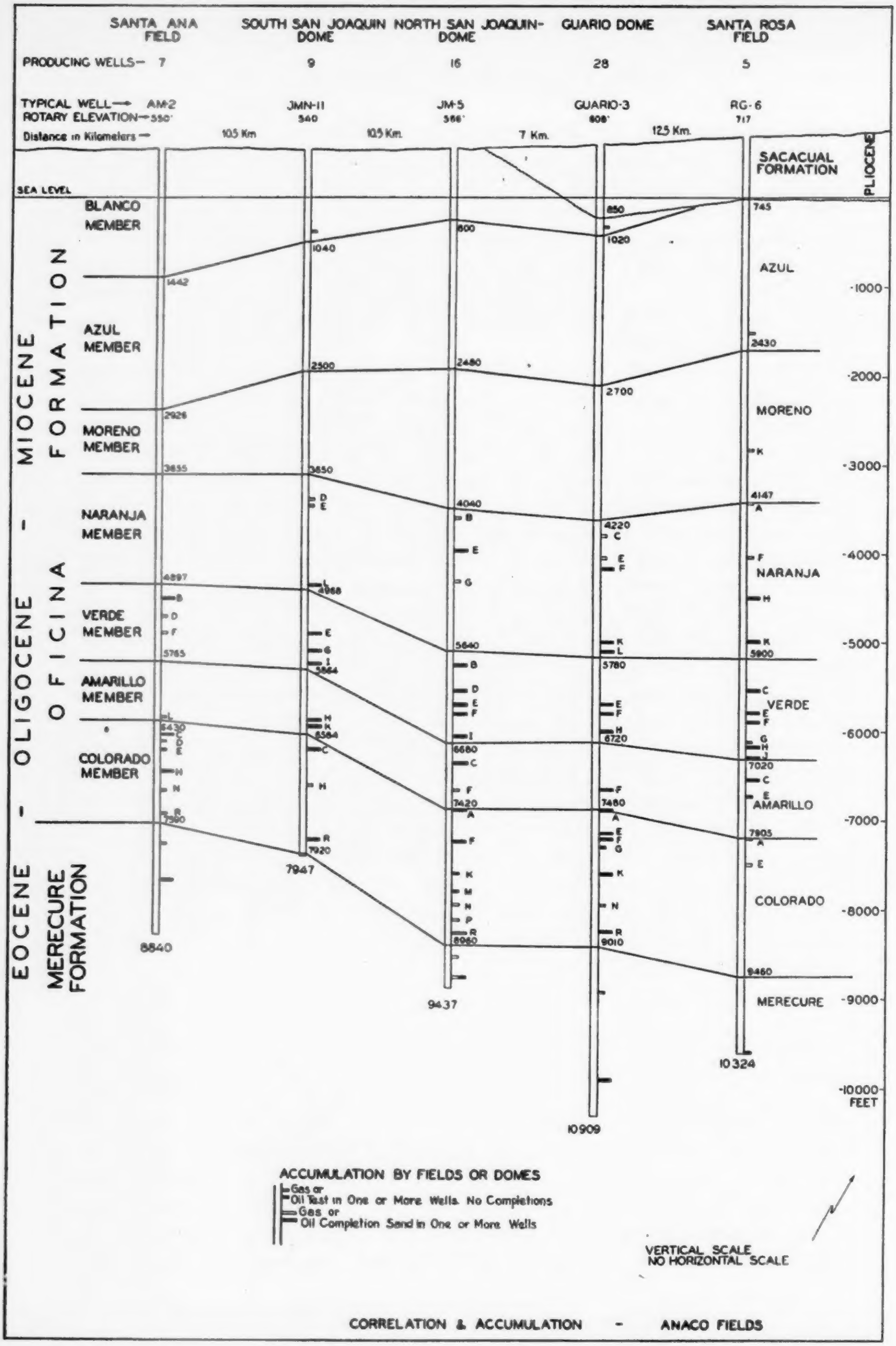


FIG. 11.—Correlation and accumulation, Anaco fields.

in the Colorado member. Finally, porous sandstones near the top of the Merecure formation have yielded gas or oil in every well in which this formation has been tested (2 of 15 wells entering the Merecure have not been tested). The relative position of the various tested sands in the stratigraphic section is shown graphically, by domes, in Figure 11.

OFICINA FORMATION

Each of the many sand bodies in this formation is separated from other sand bodies by laterally continuous shales and constitutes an individual reservoir. This fact focused early attention on sand correlation. Most of the individual sand bodies in one well section could be readily correlated from well to well by means of electric logs, and a single system of sand nomenclature was developed and used throughout the area. The sand nomenclature adopted was based on the assignment of alphabetical letters to individual sands by members (Verde, Amarillo, Colorado, *et cetera*)—the uppermost sand in any member being the "A" sand *et cetera*. It should be noted, however, that the use of an equivalent sand name, in Santa Ana and Santa Rosa for example, does not imply that a particular sand blankets the entire area between Santa Ana and Santa Rosa. The fact is that individual sand bodies are not, as a rule, widespread; they invariably seem to shale-out with distance. Not one Oficina sand is continuous throughout the length of the Anaco area, and few of them are present throughout the extent of any field or dome. Locally, equivalent sand names from well to well connote equivalent and single sand bodies; but in a regional sense, equivalent sand names merely mean that the sands are in essentially equivalent positions within the stratigraphic section.

The uppermost oil test to date has been the Naranja E sand. In the Oficina formation, 28 different sands (different stratigraphic equivalents) have produced oil and several have shown gas in high positions but have not been tested downdip from the gas. It is conservatively estimated that at least 50 different Oficina sands will be oil productive by the time the area is fully drilled. The oil-productive sands range from about 5 feet to 82 feet in net sand thickness with an average thickness of 20 feet. These sands are separated by well developed shale breaks which constitute the major part of the section. Representative wells throughout the area indicate an average of 8 per cent sandstone and 92 per cent shale (and other minor constituents) in the Naranja, Verde, Amarillo, and Colorado members.

Electric-log correlation has allowed the preparation of detailed structure-isopach maps for all of the various Oficina sands on all of the domes. Two such maps (Figs. 9 and 10) are included in this report in the section on structure. These maps depict the Verde I sand and the Colorado A sand, the two largest producers in the area to date. These maps illustrate the statement that individual sand bodies do not blanket the area. The Verde I sand is developed throughout the San Joaquín south dome, but pinches out eastward in the middle of the San Joa-

quín north dome. This sand is not developed on the Guario dome or in the Santa Rosa field, and is only very poorly developed in the Santa Ana field. The Colorado A sand on the Guario dome has one of the thickest productive developments of the area, but pinches out on the San Joaquín north dome and is absent over the San Joaquín south dome and in the Santa Ana field. The Colorado A sand is also absent northeast of the Guario dome in the Santa Rosa field. Following are additional examples of sand lenticularity.

1. Verde Lower B channel sand, as much as 46 feet thick in nearly straight line from JM-12 through JM-20, JM-25, and JM-28, on San Joaquín north dome. Not commercially developed elsewhere
2. Verde G sand developed in JMN-1, JMN-3, and JMN-7, but absent in rest of San Joaquín field. Only poorly developed in Santa Ana and has only one good development (24 feet net sand in RG-2) in Santa Rosa
3. Amarillo D sand completely absent in Santa Ana, but has thick though spotty developments in rest of area
4. Colorado C sand has thick development (± 60 feet) in Santa Ana field and in JMN-3, but not present on northeast

The conclusions follow that Oficina reservoirs in the Anaco area are usually lenticular sand bodies of limited areal extent, and though accumulations in these reservoirs are related to the domal nature of the structures, sand pinch-out is commonly an important supplementary factor. At present only a few places are known where normal faulting divides sand bodies into segments or otherwise controls accumulation.

The general lithologic character of pay sands in the Oficina formation of this area may be summarized as follows. The Colorado A sand on the Guario dome is fine-grained to medium-grained, massive, clean, well sorted, friable, and porous, with permeabilities commonly in excess of one darcy. The Verde I sand on the San Joaquín domes is fairly hard, dirty, fine-grained to coarse-grained, gritty sandstone with carbonaceous and shaly stringers throughout. Cores of the Amarillo F sand on the Guario dome and cores from a few other horizons throughout the area have indicated fine-grained to medium-grained, fairly soft, massive, clean, friable sandstone bodies with good permeabilities and with porosities of 22–26 per cent. However, many of the oil-producing beds of the area are fairly hard, somewhat calcareous, fine-grained, silty, dirty, laminated sandstones with porosities of 18–20 per cent and permeabilities of nearly 50 millidarcys. A few of the deeper Colorado sands are hard, dense, and tight, approaching the lithologic character of much of the underlying Merecure formation.

Schlumberger electric data in the Oficina formation warrant special comment. The better sands commonly show resistivities clearly indicative of the presence of oil or gas, or of the presence of water. But many of the other possible pay sands are hard and dirty, and contain comparatively high percentages of formation water with salinities that are low for oil-field waters (Table V). In these cases it is difficult to interpret fluid content solely from the electric log. Some oil sands have poor resistivity developments and some water sands appear resistive. The self-potential curve is also difficult to interpret because of the lack of strong contrast between the salinity of the formation water and the salinity of the water in the

drilling mud. As a result, the self-potential curve lacks sharpness, and is hardly developed at all if low-water-loss mud has inhibited the electro-filtration effect. Under some conditions the resistivity curve seems to give a much sharper and truer outline of sand limits than does the self-potential curve, and has been used as a source of supplementary information in estimations of net sand.

MERECURE FORMATION

Merecure oil-producing beds are hard, fine-grained to coarse-grained sandstones and grits, light gray to dark gray in color, and generally massive to poorly bedded. Secondary growth of quartz grains is characteristic. Electric-log correlations through all excepting the upper 200 feet of this formation are commonly indefinite and unsatisfactory even between relatively close wells. The distribution of sand and shale in this formation from well to well seems to be erratic, suggesting that many of the shale breaks apparent in a section must be of limited areal extent. Representative Merecure sections contain about 50 per cent sandstone and about 50 per cent shale and claystone.

A theory has been suggested that pictures the Merecure as a very thick sand body with irregular and generally non-continuous lenses of shale and claystone. This theory implies that successive sand bodies in the Merecure formation in a well section may have more or less free communication with each other a short distance away from the well bore. If so, major accumulations are not limited by every apparent shale break. Perhaps only a few of the many shale breaks in one section are sufficiently continuous and widespread to control major accumulations. Actually, only 15 wells have reached the Merecure, and none of these has gone completely through it. So far, aside from several questionable tests where bad cementation is suspected, the sequence of reservoir contents within the entire Merecure formation explored in a well section has been the typical sequence of gas, oil, and water. Gas sands have not been found below oil sands or below water sands, nor have oil sands been found below water sands. The Guario No. 3 log presented in Figure 6 is typical. No obvious barrier defining the base of one productive reservoir and the top of a second productive reservoir has yet been identified in a single well. It may be that no well has been drilled deep enough into the Merecure to tap a second reservoir. Verification or denial of this theory must await additional information.

The production results that have been obtained from the Merecure warrant further exploratory drilling. As yet, there is insufficient information to allow the drawing of structure-isopach maps; therefore, little can be said about the size, shape, or character of the reservoirs excepting that they seem to be much larger than the reservoirs in the Oficina formation.

The formation water in the Merecure (Table V) is saline, commonly containing 15,000–18,000 parts per million of chloride ion in 27,000–30,000 ppm total dissolved solids. Despite this salinity, electrical resistivity curves have been of little value in differentiating salt-water horizons from horizons containing oil or

gas. All sands in this formation appear resistive—even those that produce 100 per cent salt water when tested (Fig. 6). It is thus fairly certain that the resistivities are caused by the siliceous cementation and dense character of the Merecure rather than by fluid content.

Oil staining in standard cores has been useful in selecting intervals for individual testing for production. This testing is usually done after cementing casing on bottom, and beds are tested from the bottom up by successive squeeze and plug-back jobs. The better Merecure producing beds have porosities of 15–20 per cent, and permeabilities of 100–300 millidarcys. The productivity of this formation may locally be aided by jointing which has been noted in many of the cores.

GENERAL FEATURES

All of the hydrocarbon reservoirs of the Anaco area fields produce either 34°–47° API wax oil, or condensate, or both. The wax-oil reservoirs, all of which have gas caps, produce with gas-oil ratios as low as 600 cubic feet per barrel, and the condensate reservoirs, some or all of which may have downdip oil zones, produce as much as 1,000 barrels of condensate per day with gas-oil ratios of 10,000–15,000 cubic feet per barrel. Present data indicate that the most prolific condensate producers are in the Oficina formation, as emphasized by tests in AM-2 (Fig. 4).

Although one or two near-surface cores in Santa Ana No. 1 showed tiny areas of asphaltic oil staining, and although a streak of tar sand was reported from within the Colorado H horizon of Rincón No. 1, it now seems probable that important accumulations of black heavy tar oils are not present in this area. This absence of tar oils in the Anaco fields is particularly noteworthy as this type of oil is rather common in the producing fields of the Greater Oficina area on the south, and is the only type of oil that has been found in the broad tar belt south of the Greater Oficina area. The rather extreme conditions of temperature and pressure that prevail in the reservoirs along the Anaco trend can not alone be the cause for the absence of tar oils in this area as tar oils are present in the Greater Oficina area at reservoir temperatures of 200°F. and at pressures of more than 2,600 psi.

The problems of the source of the oil and gas, and of their migration, are open to question, but the thought presently favored for at least the Oficina formation is that these oils and gases originated in the shales in fairly close vertical proximity to the sand reservoirs in which they are now trapped. The fact that all of the oils are typically wax oils admittedly suggests a common source bed, but the following interesting distribution of oil sands and gas sands through the stratigraphic section has been noted.

I. Oficina formation
1. Blanco, Azul, and Moreno members seem to contain gas sands only—no dark oil to date
2. Upper and middle parts of Naranja member include sands with large gas caps and thin or no oil zones
3. Basal part of Naranja member, all of Verde and upper part of Amarillo member contain sands with small gas caps and thick (as much as 1,400 feet) oil columns
4. Colorado member includes large gas caps and relatively thin (±300 feet) oil columns

II. Merecure formation
1. Data suggest very thick gas caps (±1,200 feet) and apparently thin (±300 feet) oil columns in part of formation explored to date (base not reached)

Core examinations indicate that Group 3 contains a much larger percentage of marine beds than any other part of the section. This association of the thick oil columns (Group 3) with the most marine part of the stratigraphic section, and the occurrence of gas only, or of thick gas caps with only thin oil columns, in the more brackish parts of the section, suggest that only a minimum of vertical migration has occurred. The hydrocarbons now found in the reservoirs seem to be in accord with the environment and origin of stratigraphically proximate beds. Furthermore, the interval of thick oil columns (Group 3) is both underlain and overlain by intervals predominantly containing gas—a fact that would be hard to explain by vertical migration of oil and gas from some common underlying source. Finally, the persistence of the waxy character in all of the oils, and the absence of black low-gravity oils and tars, could be explained by the continued recurrence (or lack of occurrence) in this locality of some particular features of environment of deposition through the time that the oil-productive part of the section was being deposited.

Actually, the strongest evidence in favor of origin in beds closely associated with the present reservoirs is found in the equivalent formation on the south in the Greater Oficina area. Here some wax-oil reservoirs are present in all parts of the Oficina formation and these reservoirs are interbedded with non-waxy reservoirs and are even found between tar-bearing reservoirs; this lack of sequence seems to eliminate all possibilities of vertical migration from a common course.

RESERVOIR TEMPERATURES

Reservoir temperatures are high in the Anaco area fields. The temperatures in almost all of the reservoirs currently on production are in excess of 190°F. and range upward to 276°F. Figure 12 presents depth-temperature curves for the area based principally on spot temperatures obtained in the running of bottom-hole-pressure instruments in many wells. These curves begin at an observed near-surface temperature of 86°F. and pass downward through more than 10,000 feet of sedimentary section lithologically favorable for the accumulation of oil. The three curves together indicate the general range of temperatures for the Anaco area. The comparatively few values available from Santa Ana lie on the right-hand curve, many San Joaquín temperatures fall near the central curve, while Guario and Santa Rosa temperatures favor the left-hand curve. The gradients indicated in Figure 12 between the surface and 5,500 feet subsea vary from 1°F. in 40 feet to 1°F. in 48 feet of increased depth. These gradients are not exceptional for oil country.

The slight change in gradient suggested at depth in Figure 12 seems to fall somewhat above the Oficina-Merecure formational contact but may still reflect the presence of the thick, widespread Merecure sandstone in the stratigraphic section.

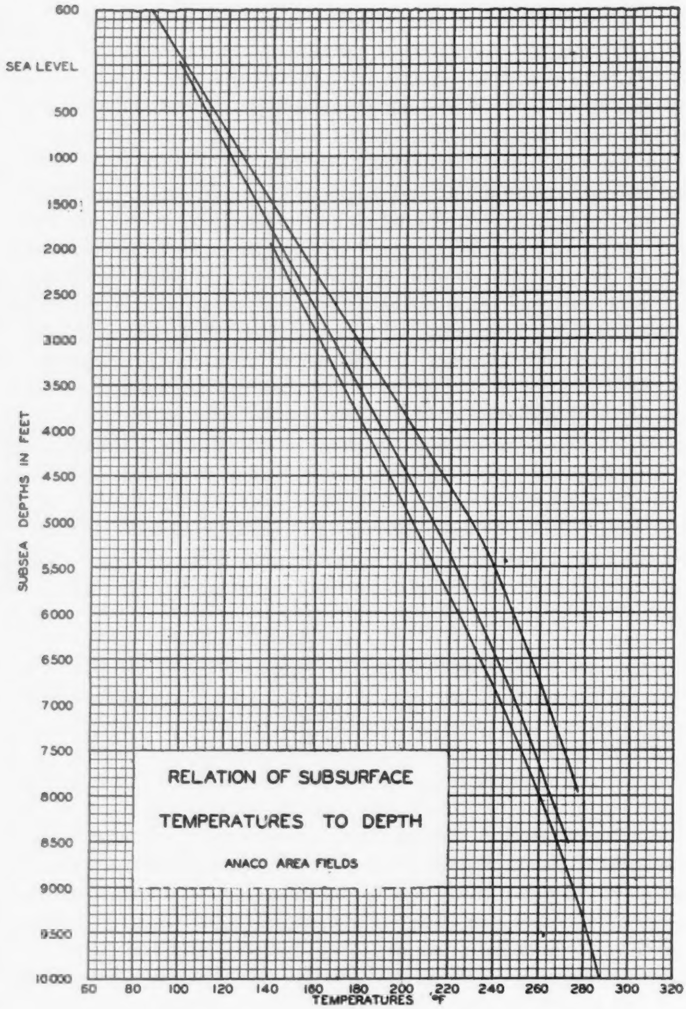


FIG. 12.—Relation of subsurface temperatures to depth, Anaco fields.

Subsurface temperatures in the Anaco area are definitely higher than those encountered in producing areas both north and south in the same basin, and these higher temperatures must certainly be related to the localized, short, sharp overthrusting and folding that resulted in the Anaco trend itself.

RESERVOIR PRESSURES

Virgin pressures in the individual reservoirs of Anaco area fields are plotted in Figure 13 against depths subsea. In every reservoir in which the depth of the oil-water contact is known, the point plotted is the virgin pressure at oil-water contact depth. In those cases where the oil-water contact is not known, the point shown is the virgin pressure at the mid-point of the producing interval. The dashed line shows hydrostatic pressure for the area at the calculated gradient of 43 psi per 100 feet. The points plotted in Figure 13 are not related one to another on any straight-line gradient. Many of the points are 500–1,000 psi in excess of hydrostatic pressure. Such pressures and pressure relationships are abnormal. An explanation of these abnormal pressures must be found in the structural history and geologic setting of the area.

Almost all of the abnormal pressures are in the Oficina formation wherein porous, permeable sand bodies comprise only 8 per cent of an otherwise shaly section, and are spaced at rather wide intervals through that section. Furthermore the individual sand bodies are limited in area. The abnormal pressures found on the fluids in these bodies must be hydrostatic pressure plus varying increments of rock pressure. If, after a considerable depth of burial, permeability barriers in the stratigraphic section became such that fluids (including water) expelled from the shales as a result of additional compression and compaction, were forced into these already completely filled sand bodies and could not escape therefrom, increments of rock pressure would be transmitted to the fluid contents of these sands. The amount of additional pressure so added to each reservoir would depend on (1) the size, position, and character of the sandstone body, (2) the time that the complete seal first became effective, and (3) the pore content of the sandstone at that time. These factors would vary from reservoir to reservoir and these variations could result in the irregular depth-pressure relation shown in Figure 13.

If temperature changes occurred subsequent to the time of sealing, they also would be reflected in the ultimate pressures attained.

Virgin pressures measured in the underlying thick Merecure sandstone, which, in contrast to the aforedescribed Oficina sandstones, is widespread and continuous over a very large area, have been with few exceptions fairly close to the simple hydrostatic pressure.

RESERVOIR CONTENTS

GAS

Most of the hydrocarbon reservoirs in the Anaco area have fairly large gas caps, and some of the reservoirs are essentially all gas. In proving reservoir con-

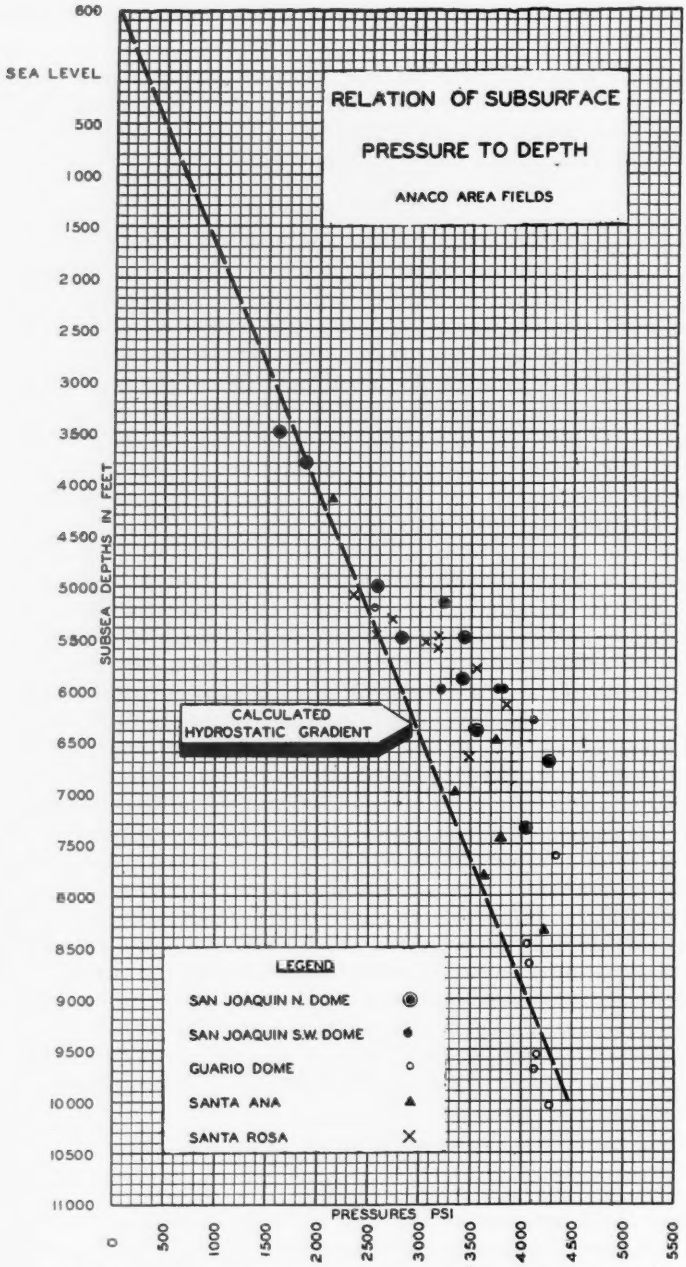


FIG. 13.—Relation of subsurface pressure to depth, Anaco fields.

tent, and in establishing the limits of gas caps, production tests of short duration have been made which resulted in appreciable condensate production at gas-liquid ratios ranging from 12,000 to 200,000 cubic feet per barrel. Reservoir pressures and reservoir temperatures in the area are abnormally high, and retrograde condensation phenomena have been noted. In fact, all indications point to considerable reserves of gas and condensate. But the operators have chosen first to exploit the liquid oil found downdip, and as of January 1, 1947, only 600,000 barrels of straight condensate had been produced. This amounted to less than 2 per cent of the total oil recovery from these fields at the same date.

An example of an interesting condensate horizon is the Colorado "H" sand in well AM-2, Santa Ana field, where production tests under single-stage separation (separator pressure 830 psi) resulted as follows.

Choke (Inch)	*Liquid Per Day (Barrels)*	*°API*	*Gas-Liquid Ratio*	*THP*
3/8	460	52.5	13,550	2,200
5/8	985	49.8	14,190	2,025

A laboratory study of this reservoir gas indicated that its dew-point pressure was equivalent to the virgin reservoir pressure (3,745 psi). The experiments further indicated that if the pressure in this reservoir declines with production, the reservoir gas will become progressively leaner in heavy hydrocarbons as liquids condense on the reservoir rock, until a pressure of 1,000 psi is reached. At pressures below 1,000 psi this dew on tbe reservoir rock will commence to revaporize and the reservoir gas will again become richer. Decrease in pressure in this reservoir will, therefore, result in isothermal retrograde condensation. An analysis of the virgin, single-phase, saturated reservoir gas in mole percentages is here given.

	Percentage
Carbon dioxide	4.78
Methane	69.21
Ethane	9.03
Propane	6.65
Iso-butane	1.55
N-butane	2.10
Iso-pentane	0.46
N-pentane plus	6.22
	100.00

Some of the physical properties of the separator liquid obtained on production of this horizon (Colorado "H" of AM-2) are given in the fourth column of Table IV-A. The second and third columns of this table list similar data on the liquid obtained on production from another comparatively rich condensate horizon in the Santa Ana field. Some distillation data are included.

As an example of a leaner gas, production tests of a Merecure horizon in AM-1, Santa Ana field, under single-stage separation (separator pressure, 470 psi) resulted as follows.

Choke (Inch)	*Liquid Per Day (Barrels)*	*°API*	*Gas-Liquid Ratio*	*THP*
3/16	28	51.0	64,400	—
1/4	44	50.3	69,000	2,700
3/8	65	50.3	60,000	2,600

Laboratory examination of samples of this particular reservoir gas indicated that the dew-point pressure was 1,600 psi in contrast to the reservoir pressure which was 3,350 psi. As the pressure in this reservoir declines with production, no liquid will condense on the sand grains until the dew-point pressure is reached. Below the dew-point pressure, condensation will occur, and although the laboratory test did not determine the pressure at which revaporization of this condensate commences, the reservoir temperature of 269°F. indicates that it will commence. Therefore, if exploitation of this reservoir is accompanied by a decline of pressure below the dew-point pressure, this reservoir will also exhibit isothermal retrograde condensation. An analysis of this virgin, single-phase, but undersaturated reservoir gas in mole percentages is here given.

	Percentage
Carbon dioxide	14.69
Nitrogen	0.00
Methane	77.66
Ethane	3.45
Propane	1.33
Iso-butane	0.22
N-butane	0.32
Iso-pentane	0.17
N-pentane	0.33
Hexanes	0.48
Heptanes plus	1.35
	100.00

All of the gas reservoirs of the area may not display retrograde phenomena such as described here, but, without doubt, many of them will. These examples call attention to the complexities and potentialities of the gas resources of this area, and to the resultant necessity of having detailed laboratory information on these reservoir gases prior to considering their active exploitation. Pressure maintenance, cycling operations, or other special procedures may be indicated.

To date, 600,000 barrels of straight condensate have been taken from seven wells from the fields discussed. At first, such production was taken only to supply fuel for some of the early drilling operations. Later a few wells were purposely taken down to test the Merecure and some of these found condensate. Production experience in one Merecure well indicated that the condensate was somewhat corrosive. As of January 1, 1947, only two wells in these fields were exploiting condensate production. Almost all of their liquid was being run through a topping plant making gasoline for local company consumption.

OIL

All the dark oils from the many sands of the Oficina formation have somewhat comparable physical characteristics. They are dark green and their gravity ranges

from 37° API to 47° API. All are typical wax oils, commonly containing 5–20 per cent paraffine wax by weight. Pour points vary from 75°F. to 95°F. Sulphur contents are low. Physical properties of nine such oils from individual horizons in the Santa Rosa field are presented in Table IV-B. Physical properties of an oil from one such horizon in the Santa Ana field are presented in Table IV-A.

Dark oils have also been found in the underlying Merecure formation in five wells. Samples of Merecure oil from Santa Ana, Rincón Largo, Guario, and Santa Rosa have been examined by the Mene Grande Oil Company. The gravities of these Merecure oils range from 33.4° API to 37° API. Wax contents range from 19 per cent to more than 23 per cent by weight, and pour points range from 90°F. to 95°F. These oils are of slightly lower gravity, higher wax content, and higher pour point than oils from the Oficina formation. Physical properties of some of these Merecure oils from individual horizons are given in Tables IV-A and IV-B.

Table IV-C lists the physical properties of crudes representative of the production from the individual fields and ownerships during the year 1945. The final column in this table presents data on a composite sample of all production from this area during the same year, and is fairly representative of the area's pipe-line product called "San Joaquín Blend."

The persistence of fairly high-gravity wax oils and condensates in the stratigraphic section, and the absence of black, low-gravity oils and tars, is noteworthy. Whether these are indications of a single source for all of the oils, or an indication of monotonously similar environments of deposition, throughout the time of deposition, or are somehow simply reflections of the present extremes of subsurface temperatures and pressures under which the hydrocarbons exist in the fluid state in their respective reservoirs, are moot questions discussed elsewhere in this report.

Studies of the physical characteristics of the individual reservoir oils (subsurface samples) have been hindered somewhat by the exceptionally, high temperatures required of the analytical equipment. As a result, none of the really high-temperature horizons has yet been studied, but results from some of the more shallow producing zones are available. Some of these data here tabulated afford information about the order of magnitude of some shrinkage factors and dissolved gas factors for use in reserve estimates and in interpreting production problems. Many more such data are required, and will be obtained as equipment becomes available.

Temperature (°F.)	*Saturation Pressure* (*P.S.I.*)	*Gas Solubility* (*Cu. Ft. per Bbl.*)	*Shrinkage Factor*	*Production Gravity* (°*A.P.I*)
192	2,225	875	.65	41.4
205	2,140	1,050	.59	41.7
222	2,735	1,334	.53	40.9
223	3,450	2,040	.44	40.8
224	3,330	2,003	.41	43.0

TABLE IVa
PHYSICAL PROPERTIES OF
CRUDE OILS FROM INDIVIDUAL HORIZONS
SANTA ANA FIELD

SAND	Verde "B"	Colorado "C"	Colorado "C"	Colorado "H"	Mereure	Mereure
Well	AM-1	AM-1	AM-1	AM-2	AM-3	RL-1
Gravity, API	40.5	51.9	53.7	52.1	33.4	34.6
Sulfur, B., percent	0.24	0.02 (d)	0.02 (d)	0.10	0.29	0.43
Saybolt Viscosity	35.4 (b)	29.0 (a)	29.0 (a)	-	44.8 (b)	40.3 (b)
Pour Point, F	95	-10	-10	-	90	95
Flash Point, O.C., F	below 60	below 60	below 60	-	below 60	90
Color	dark green	-	-	-	green	brnh. green
% Motor Gas Distillate (over-392 F)	37.1	70.0	75.2	73.1	12.4	24.3
Gravity, API	58.7	56.6	58.3	57.2	48.9	53.8
Octane Number, CFR-ASTM	56	52	55	64	59	59
% Heavy Blend Distillate (392-428 F)	2.7	5.9	5.2	3.6	3.0	3.4
Gravity, API	43.9	45.4	44.7	41.1	41.2	40.6
% Light Gas Oil Distillate (428-518 F)	11.3	13.4	10.7	9.7	11.0	10.8
Gravity, API	37.7	41.7	41.3	35.7	35.6	35.3
% Bottoms	48.1	10.2	8.3	12.7	73.4	61.1
Gravity, API	30.2	36.6	37.1	33.7	30.5	27.3
Viscosity	41.5 (c)	43.4 (a)	44.2 (a)	41.4 (b)	67.1 (b)	83.7 (b)
Sulfur, B., percent	0.35	0.11	0.17	0.63	0.35	0.63
Pour Point, F	120	55	65	85	115	110
Carbon Residue	1.41	0.05	0.13	0.04	1.07	2.05
% Loss	0.8	0.5	0.6	0.9	0.2	0.4
% Paraffin wax (by weight)	21.6	0.2	0.2	x	23.2	19.2
% Asphaltic hydrocarbons	-	0.02	0.03	0.02	2.0	4.0
Base of Crude, USBM	-	-	-	-	Intermediate-Paraffin	Intermediate

(a) Viscosity at 100 F (b) Viscosity at 122 F (c) Viscosity at 210 F (d) Sulfur by lamp method

TABLE IV b

PHYSICAL PROPERTIES OF
CRUDE OILS FROM INDIVIDUAL HORIZONS
SANTA ROSA FIELD

SAND	NARANJA H	NARANJA K	VERDE C	VERDE E	VERDE F_L	VERDE H	VERDE J	COLORADO A	COLORADO E	MERECURE	COMPOSITE
Well	RM-1	RG-6	RG-6	RG-2	RG-4	RG-5	RG-2	RM-1	RM-1	RG-6	
Gravity, API	46.4	41.4	41.5	41.8	42.7	41.2	44.1	47.0	44.4	34.4	45.5
Sulfur B., percent	0.18	0.15	0.19	0.14	0.09	0.15	0.09	0.21	0.10	0.29	0.12
Saybolt Viscosity	32.3 (a)	40.1 (a)	39.9 (a)	35.1 (a)	35.7 (a)	34.8 (a)	34.5 (a)	31.0 (a)	34.0 (a)	43.8 (b)	33.0 (a)
Pour Point, F	75	85	85	70	75	95	85	50	60	95	75
Flash Point, O.C., F	below 60	below 60	below 60	below 60	below 60	below 60	below 60	below 60	below 60	below 60	below 60
Color	dark green	dark green	dark green	dark green	dark brown	dark green	green	----------	----------	dark green	olive green
% Motor Gas Distillate (over 392 F)	44.4	37.2	37.2	40.3	40.7	36.1	42.4	59.7	55.1	15.4	45.3
Gravity, API	58.7	57.8	58.5	56.6	57.6	58.6	59.6	55.9	54.0	51.4	59.2
Octane Number, CFR-ASTM	52	59	56	55	59	59	63	62	59	59	62
% Heavy Blend Distillate (392-428 F)	4.3	3.4	3.4	3.3	3.8	3.0	3.6	4.6	3.6	3.5	3.1
Gravity, API	46.0	43.0	43.8	43.0	42.5	42.4	41.6	40.2	41.0	40.8	41.6
% Light Gas Oil Distillate (428-518 F)	13.5	10.2	10.8	12.3	11.3	10.2	10.4	12.2	14.2	9.2	9.2
Gravity, API	42.0	37.0	37.8	36.7	36.3	36.1	35.5	35.3	35.7	35.4	36.3
% Bottoms	37.4	46.8	46.0	42.3	42.1	48.3	42.2	23.2	26.5	69.8	38.6
Gravity, API	33.2	29.9	30.4	30.1	20.2	29.8	30.5	32.9	32.5	30.4	30.2
Viscosity	54.6 (b)	84.9 (b)	87.1 (b)	62.2 (b)	77.5 (b)	88.3 (b)	62.9 (b)	46.0 (b)	47.0 (b)	62.5 (b)	60.6 (b)
Sulfur B., percent	0.38	0.20	0.32	0.26	0.17	0.25	0.14	0.24	0.13	0.36	0.17
Pour Point, F	105	120	115	115	115	115	115	95	100	115	115
Carbon Residue, percent	0.83	1.60	1.72	1.29	1.04	1.70	0.95	0.20	0.30	1.41	1.07
% Loss	0.4	2.4	2.6	1.8	2.1	2.4	1.4	0.3	0.6	2.1	3.8
% Paraffin Wax (by weight)	5.5	15.8	20.1	9.2	14.3	20.9	14.0	3.3	3.6	19.1	16.5
Base of Crude, USBM	not available	not available	not available	not available	not available	not available	intermediate paraffin	intermediate naphthene	intermediate paraffin	intermediate paraffin	

(a) Viscosity at 100 ° F (b) Viscosity at 130 ° F

TABLE IVc
PHYSICAL PROPERTIES OF
REPRESENTATIVE PRODUCTION FROM
INDIVIDUAL FIELDS, ANACO AREA
1945

FIELD	SANTA ANA	SAN JOAQUIN				ROBLE	SANTA ROSA
Dome	-	Southwest	North	Guario		Roble	-
Operator	MGO-TPC	Creole	Creole	Creole	Socony	Creole	MGO
Gravity, API	35.4	40.3	43.0	46.2	44.1	53.1	44.1
Sulfur, B., percent	0.18	0.11	0.19	0.12	0.13	0.08	0.16
Viscosity, Saybolt	48.3 (a)	42.4 (a)	35.4 (a)	33.0 (a)	33.0 (a)	29.3 (a)	36.0 (a)
Pour Point, F	75	85	90	85	75	50	85
Flash Point, O.C., F	below 60	below 60	below 60	below 60	below 60	below 60	below 60
Color	dark green	dark green	dark green	dark green	dark green	-	dark green
% Motor Gas Distillate (over - 392 F)	20.5	33.4	40.1	45.2	44.8	61.6	41.9
Gravity, API	51.8	55.7	58.9	60.4	59.0	60.6	59.1
Octane Number, CFR-ASTM	59	62	61	62	61	63	60
% Heavy Blend Distillate (392-428 F)	3.1	2.9	3.2	3.2	3.6	3.2	3.4
Gravity, API	41.3	41.3	41.7	41.2	41.9	41.8	42.3
% Light Gas Oil Distillate (428-518 F)	7.3	10.3	9.9	9.8	10.5	7.3	8.3
Gravity, API	36.6	35.9	36.1	35.9	36.1	36.3	37.2
% Bottoms	67.5	51.1	42.1	36.5	40.6	20.0	41.0
Gravity, API	30.7	30.2	30.1	30.6	30.5	31.3	30.2
Viscosity	61.2 (b)	66.9 (b)	66.8 (b)	61.1 (b)	60.0 (b)	58.4 (b)	65.6 (b)
Sulfur, B., percent	0.30	0.15	0.15	0.15	0.26	0.14	0.23
Pour Point, F	105	120	120	120	110	105	115
Carbon Residue, percent	1.20	1.25	1.30	1.21	1.15	0.76	1.49
% Loss	1.6	2.3	4.7	5.3	0.5	7.9	5.4
% Paraffin Wax (by weight)	10.3	21.7	14.2	12.3	13.9	4.5	13.1

(a) Viscosity at 100 F (b) Viscosity at 130 F

TABLE V

WATER ANALYSES

ANACO AREA FIELDS

SAND	VERDE E	VERDE F	AMARILLO A	AMARILLO C	AMARILLO D	AMARILLO F	COLORADO A	COLORADO G	COLORADO K	COLORADO R	MERECURE	MERECURE
Well	Guario-15	Guario-15	Guario-11	Typed	Typed	Guario-11	Guario-2	Guario-12	Guario-5	JM-8	Guario-3	Guario-3
Parts per million												
Total dissolved solids	12,323	10,953	15,480	12,260	12,905	11,223	10,147	13,585	8,745	10,239	29,662	27,077
Sodium (a)	3,937	3,421	5,077	4,000	4,155	3,404	3,025	4,514	2,763	3,600	11,100	10,080
Calcium	111	70	146	90	50	55	42	45	19	30	370	360
Magnesium	100	36	21	10	0	0	20	45	6	7	32	41
Chloride	3,510	2,740	5,240	3,800	3,400	1,884	1,594	4,702	1,990	4,018	17,400	15,850
Sulfate	188	238	154	160	100	252	169	117	63	18	-	-
Bicarbonate	4,477	4,448	4,782	4,200	5,200	5,630	5,297	4,107	3,904	2,385	780	746
Carbonate	0	0	0	0	0	0	0	0	0	181	-	-
Palmer Classification												
Primary Salinity	58.4	53.0	65.9	61.6	53.5	38.8	35.8	66.8	47.4	71.6	95.8	95.3
Secondary Salinity	-	-	-	-	-	-	-	-	-	-	1.6	2.0
Primary Alkalinity	33.8	42.8	30.2	35.4	45.2	59.4	61.4	30.2	51.5	27.0	-	-
Secondary Alkalinity	7.8	4.2	3.9	3.0	1.3	1.8	2.7	3.0	1.1	1.4	2.6	2.7

(a) In every case sodium was estimated by arbitrarily balancing reaction values.

NOTE: The above analyses are included by courtesy of the Socony Vacuum Oil Company of Venezuela and of the Creole Petroleum Corporation. Most of the analyses were made in Socony's Laboratory in their Guario Camp, by M. L. Griffin.

FORMATION WATER

Table V presents analyses of 12 formation waters representative of the productive range of the stratigraphic section. The analyses are arranged from left to right in the order of increasing stratigraphic depth. They indicate that all of the waters in the Oficina formation are brackish, containing only 10,000–15,000 parts per million total dissolved solids, 1,500–5,000 parts of which are chloride ion. In contrast, the waters of the underlying Merecure formation are definitely much more saline, containing 25,000–30,000 parts per million total dissolved solids, 15,000–18,000 parts of which are chloride ion. Oficina formation waters exhibit primary alkalinity in contrast to the secondary salinity of Merecure formation waters. A similar change in correlative character is found at depth in the Greater Oficina area on the south, but the Merecure formation is not known in that area although it is considered possible that the basal Oficina "U" sands are equivalent to a part of the Merecure formation. Almost all of the analyses presented in Table V were made in the Guario laboratory of the Socony Vacuum Oil Company. Such analyses are useful to the operators in identifying the sources of waters obtained on production tests preparatory to completing a well, and in identifying the sources of waters that later break into wells to contaminate production. Waters from closely adjacent beds have been successfully identified.

DRILLING AND COMPLETION PRACTICE

All of the 71 wells in the Anaco fields have been drilled by the rotary method, usually by steam rigs. Final depths range from 3,934 (JM-15) to 10,909 feet (Guario No. 3) and may be summarized as follows.

Feet	*Wells*	*Feet*	*Wells*
Less than 4,000	1	7,000– 8,000	16
4,000–5,000	0	8,000– 9,000	7
5,000–6,000	9	9,000–10,000	5
6,000–7,000	26	10,000–11,000	7

Objectives have been as varied as the depths, but prior to 1946 and aside from the JM-15 Naranja E shallow completion previously mentioned, the minimum objective has been the base of the Verde member. During 1946, exploitation on the Guario dome has concentrated on the 5,000–6,000-foot completions through the Naranja member. The maximum objective to date has been the Merecure formation and 15 wells have gone through at least a part of this formation. These wells are divided as follows: 6, Santa Ana field; 1, South San Joaquín dome; 2, North San Joaquín dome; 4, Guario dome; and 2, Santa Rosa field. Completion times vary with the objective and range from nearly 3 years for AM-3, where long fishing jobs delayed the completion, to 41 days for JM-37, which has a final depth of 5,266 feet.

Formations in the area are fairly hard and this characteristic increases markedly with depth. Hard-formation bits are customarily used at depths greater than 1,500 feet. The Merecure formation is extremely hard and progress in this formation is very slow, in places only several inches per bit. Drilling is also slowed

by the presence of 10°–25° dips which, with alternating hard and relatively soft beds, throw the holes off vertical if too much weight is applied. Extensive cores were taken in RG-1, AM-1, AM-2, JMN-1, and JM-2, but present practice is to drill the wells with little or no coring; the few cores taken are for sand analyses or for the determination of content by drill-stem testing.

Electrical surveys are usually made of the entire section, but in some wells the topmost 1,000–1,500 feet of section is not surveyed before surface pipe is run. Surveys have been run in all wells excepting RG-1. Contrary to practice in the Greater Oficina area, very few side-wall samples are taken for sand evaluation. Primary reasons for this are that all of the oil has essentially the same gravity (±40° API) and that the light-gravity wax oil does not show any great amount of staining in the small samples made available by this method; in other words, it is difficult to differentiate between an oil or a gas sand on the basis of these small samples. In fact, even the content of some conventional cores is misinterpreted.

Casing programs have varied with the companies, depths, and experience in any one area. The Creole, the largest operator, now runs 9⅝-inch casing to depths between 1,500 feet and 3,100 feet with 5½-inch casing to bottom. Depending on whether shallow gas sands are present in the particular area, strings of 18⅝-inch or 13⅜-inch casing may be used at shallow depths. Socony, the second largest operator, has standardized on 13⅜-inch at 1,500 feet, 9⅝-inch at ±6,100 feet, and 6-inch to total depth on deep wells, and 9⅝-inch at 1,200 feet, and 6-inch to total depth on shallow (±6,000 feet) wells. The Mene Grande has lately used 13⅜-inch at 1,500 feet, 9⅝-inch at 5,000–7,000 feet, with 5½-inch to bottom either now or after deepening at some later date, but will soon embark on a program with 10¾-inch at 1,500 feet, and 7-inch to bottom at least in so-called shallow (±7,500 feet) Santa Rosa wells. The last several Texas Company wells have had 10¾-inch at about 6,000 feet followed by 7-inch at final depth.

Although perforated liner was set through the bottom sand of some of the early wells, completion is almost entirely by gun perforation. Dual completions are in the majority as shown by the fact that of 65 producing wells 35 were completed dually, and a second zone has been added to several single-zone wells in work-overs subsequent to completion. Eight completions in the San Joaquín field have included more than one sand in one producing zone, but this procedure has been stopped largely because of the resultant loss in reservoir control; the last completion of this type was in 1944. The operators recognize that in the Oficina formation each sand is an individual reservoir with its own gas-oil and oil-water contacts and that these contacts may vary greatly in sands separated by only a small amount of shale; accordingly, it is standard practice to include only one sand in each producing zone. No triple-zone completions have been made in this area.

Following the entrance of water or excessive gas, some of the wells have been worked over. None of the wells is on pump or gas lift. Repressuring or pressure maintenance has not been started, but several such projects are programmed for the near future.

Occasional blow-outs have been encountered, ordinarily from shallow (1,000–3,000 feet) gas sands. RG-6 had a particularly serious blow-out which caught fire. This blow-out, from either a Merecure or a Colorado sand, occurred in the latter part of 1946 and was brought under control after being on fire for nearly 4 weeks. The well is now producing satisfactorily from sands much shallower than the source of the blow-out.

As mentioned elsewhere, 6 drilling rigs are operating in the area as of January 1, 1947. Two of these are in the Santa Ana field, 3 are on the Guario dome, and 1 is in the Santa Rosa field. In addition, one work-over rig is operating on the Guario dome. Of these rigs, the Mene Grande is operating 3, Creole 2, and Socony 1 plus the work-over rig.

PRODUCTION

PRODUCTION PRACTICES

Well spacing on the San Joaquín domes has been geometrically regular on an equilateral triangle grid system with a distance of 600 meters between wells, giving a drainage area of 77 acres per well. The wells drilled by the Creole on the Guario dome have been, in general, on this same 600-meter grid, but adjustments have been made to satisfy drainage considerations across property lines. The wells drilled by the Socony on the Guario dome have not been located on any regular grid system. Instead, the Socony has arbitrarily located wells with respect to probable positions of structure contours delineating the dome. Socony wells with few exceptions are at least 400 meters apart. In the Santa Rosa field spacing is regular on an equilateral triangle system, but with a distance of 769.8 meters between wells, giving a drainage area of 126.8 acres per well. In Santa Rosa there is already talk of breaking down this wide spacing for the so-called shallow (±7,500 feet) wells by face-centering to give a secondary grid of 444.4 meters between wells (42.3 acres) and of using an offset 769.8-meter grid for deep (±12,000 feet) wells. In the Santa Ana field half of the present wells have been drilled on a 600-meter equilateral triangle grid system that probably will be followed as exploitation progresses. The other wells are along the south edge of the Santa Ana feature on adjusted locations along a property line.

All of these data on well spacing and drainage areas refer only to surface locations. Since all wells are not completed in the same sands, drainage of individual sands (individual reservoirs) is in every case on a considerably wider spacing than these figures indicate.

Multiple-sand accumulation on the various domes was discovered early, as was the fact that each successive sand in any well was an individual reservoir entirely separate from all other accumulations in the same well, and had its own individual gas-oil and oil-water contact. Later, it was found that reservoir pressures in the individual sands throughout the section varied irregularly one from another. These facts, coupled with knowledge that permeabilities likewise vary from sand to sand, dictate the practice of producing individual sands through

individual conductors. Such a practice has been followed to date, but for a few exceptions.

In an effort to utilize existing wells while still maintaining the individuality of the producing horizons, dual-zone completions have been made wherever possible.

Each horizon from which a well produces, or has produced, through an individual conductor is locally termed a "zone." Production from each zone has been restricted by surface chokes and withdrawal rates now generally range from 200 to 500 barrels per day per zone. The wells flow the oil directly to field gathering stations, or to field manifolds and thence to gathering stations. At Santa Ana, two-stage separation is practiced with separators operating at 240 psi for the first stage and 40 psi for the second. The oil is gaged at this station and is then pumped to the Anaco tank farm of the Mene Grande Oil Company, which tank farm serves all the producing fields in the Anaco area. At San Joaquín, Creole has a gathering station on each San Joaquín dome, and a third station on the Guario dome. Creole initially practiced single-stage separation but since May of 1941, has had two-stage separation on the north dome with the separators set at 400 psi and 40 psi, respectively, and has had similar two-stage separation at its station on the Guario dome ever since that station began receiving oil in 1944. Single-stage separation at 90 psi is still in operation on the southwest San Joaquín dome. The oil is gaged at these Creole-operated stations and is pumped out to Anaco. Almost all of Socony's wells on the Guario dome flow their oil through field discharge stations with separators operating at 275 psi (first stage) and then continue to flow the oil to Anaco where it goes through a 50-psi separator (second stage) and a third separator operating at 20 psi (third stage) before being gaged in one of the two Socony 47,000-barrel floating-roof tanks. The Socony then pumps this oil to the adjacent Anaco station of the Mene Grande Oil Company for pipelining to the coast. The Socony's weaker wells flow their oil to a low-pressure single-stage separator at Guario camp, and this oil is then pumped direct to the Socony tanks at Anaco. The single station at Santa Rosa field practices two-stage separation (220 psi and 35 psi) and this oil is then pumped to the Mene Grande tank farm at Anaco.

Each of the stations mentioned is so equipped that individual production tests including rate, gravity, cut, and gas-oil ratio can be made on each zone at least as frequently as once a month. The total oil gaged at each station each month is then allocated to individual zones and reservoirs on a basis of these production tests and hours on production.

PRODUCTION STATISTICS

On January 1, 1947, 27,696,939 barrels of oil had been withdrawn from the fields here described from 66 wells, giving an average cumulative production per well of 419,650 barrels. On a basis of zones, this oil had been withdrawn from 110 zones, giving an average cumulative production per zone on that date of 251,790

barrels. More than 75 per cent of the wells and almost 70 per cent of the zones were still producing by natural flow. Artificial lifting has not yet been used. The data are classified by domes in the following table.

Dome	*Wells*	*Zones*	*Production (in Barrels)*		
			Cumulative	*Per Well*	*Per Zone*
Santa Ana	7	8	2,634,694	235,618	206,166
San Joaquín S.	9	14	4,925,611	547,290	351,829
San Joaquín N.	16	25	9,689,557	605,597	387,582
Guario	28	51	7,723,185	275,828	151,435
Santa Rosa	5	11	2,723,892	544,778	247,626

Four wells in these fields, on January 1, 1947, had already individually produced more than 1,000,000 barrels of oil as follows.

Well	*Dome*	*Production to Jan. 1, 1947 (Bbls.)*
JM-12	San Joaquín N.	1,752,852
JM-13	San Joaquín N.	1,605,442
JM-4	San Joaquín S.	1,474,628
RG-4	Santa Rosa	1,287,540

The individual zones that had contributed the most oil by the same date were the six here listed.

Well	*Zone*	*Dome*	*Production to Jan. 1, 1947 (Bbls.)*
JM-4	Verde "I"	San Joaquín S.	1,474,628
JM-12	Verde "I"	San Joaquín N.	1,103,890
JM-13	Colo. "A"	San Joaquín N.	1,037,327
AM-3	Merecure	Santa Ana	754,575
RL-2	Colo. "C"	Santa Ana	709,616
RG-4	Verde Cu	Santa Rosa	680,256

Production data for the several fields or domes are summarized in Table VI. This table lists not only the production record by years since each field has been under exploitation, but also lists the number of wells drilled, number of commercial producers, number of productive sands, range in productive depths, productive surface acres, crude-oil daily potential, on January 1, 1947, *et cetera*, all by fields or domes.

Table VII lists cumulative production for each field or dome, on January 1, 1947, by sands. This table shows for each field the vertical range of stratigraphic section from which oil has been produced, and the relative importance in each area of each part of the stratigraphic section insofar as productivity to date is concerned. Ninety-four per cent of the total production from these fields has come from the Oficina formation, and 35 per cent has come from two sands in that formation (Verde "I" and Colorado "A").

PRODUCTION PROCESSES

Pressures are declining with production in most of the larger reservoirs of the area at rates suggestive that dissolved-gas drive is the primary production mech-

TABLE VI

PRODUCTION DATA BY FIELDS OR DOMES - ANACO AREA

	SANTA ANA FIELD	SOUTH SAN JOAQUIN DOME	NORTH SAN JOAQUIN DOME	GUARIO DOME	SANTA ROSA FIELD	TOTALS
WELLS DRILLED AS OF JANUARY 1, 1947	8	9	18	28	8	71
WELLS COMPLETED AS COMMERCIAL PRODUCERS	7	9	16	28	5	65
STATUS OF WELLS AS OF JANUARY 1, 1947						
ACTIVE						
Natural Flow	6	7	12	20	5	50
Artificial Lift	0	0	0	0	0	0
INACTIVE						
Closed In Condensate or HGOR Wells	1	0	1	3	0	5
Awaiting Artificial Lift or Repairs	0	1	3	0	0	4
Awaiting Workover - HGOR, Water Cut or Dead	0	1	0	5	0	6
Suspended Awaiting Fishing Tools	1	0	0	0	0	1
Abandoned Gas Well	0	0	0	0	1	1
Abandoned Dry Holes	0	0	2	0	2	4
NUMBER OF OIL PRODUCTIVE SANDS	5	8	12	14	10	29
RANGE IN OIL PRODUCTIVE DEPTHS	4650-6790'	5470-8160'	3830-8035'	4150-10705'	5690-10384'	
RANGE IN OIL PRODUCTIVE SANDS: FROM TO & INCLUDING	Verde B Merecure	Naranja L Colorado R	Naranja E Merecure	Naranja F Merecure	Naranja H Merecure	
THICKEST OIL SAND (OFICINA ONLY)	Colorado C (82')	Colorado O (38')	Verde E (30')	Colorado A (68')	Verde E (40')	
THICKEST OIL ZONE	Colorado E (300'+)	Verde I (700')	Verde I (1400')	Naranja L (1000')	Verde C (500'+)	
RANGE IN INITIAL API GRAVITY	33°-51°	37°-54°	36°-51°	38°-53°	37°-48°	
ESTIMATED PRODUCTIVE SURFACE ACRES (OIL & GAS)	6,520	3,610	4,225	7,470	7,040	28,865
CRUDE OIL DAILY POTENTIAL JANUARY 1, 1947	3,260	1,965	4,500	10,475	2,450	22,650
PRODUCTION RECORD BY YEARS (BARRELS)						
1937	3,000	-	-	-	-	3,000
1938	8,017	-	-	-	-	8,017
1939	24,395	5,516	36,207	-	-	66,118
1940	75,790	290,827	806,735	15,923	-	1,189,275
1941	199,764	881,137	2,002,256	109,728	218,012	3,410,897
1942	44,844	245,278	592,978	128,172	382,032	1,393,304
1943	75,045	341,145	773,716	94,825	364,047	1,648,776
1944	429,070	1,092,345	2,421,278	962,048	676,109	5,580,850
1945	881,131	881,403	1,907,517	2,955,990	548,118	7,114,159
1946	953,636	687,980	1,448,870	3,486,801	536,574	7,082,343
TOTAL PRODUCTION TO JANUARY 1, 1947	2,634,694	4,925,611	9,689,557	7,783,185	2,723,892	27,696,939
PRODUCTION RECORD BY OPERATING COMPANIES						
Texas	1,649,325	-	-	-	-	1,649,325
Mene Grande	985,369	-	-	-	2,723,892	3,709,261
Creole	-	4,925,611	9,689,557	3,098,763	-	17,713,931
Socony	-	-	-	4,684,422	-	4,684,422
DRILLING RIGS - JANUARY 1, 1947						
Texas	0	-	-	-	-	0
Mene Grande	2	-	-	-	1	3
Creole	-	0	0	2	-	2
Socony	-	-	-	1	-	1

TABLE VII
ACCUMULATIVE PRODUCTION BY SANDS
AS OF JANUARY 1, 1947

PRODUCING SANDS	SANTA ANA FIELD	SAN JOAQUIN FIELD South Dome	SAN JOAQUIN FIELD North Dome	SAN JOAQUIN FIELD Guario Dome	SANTA ROSA FIELD	TOTALS BY SANDS	TOTALS BY MEMBERS	MEMBER
Naranja E			229,752			229,752		
Naranja F				101,313	170	101,483		
Naranja H					215,873	215,873		
Naranja K				105,902	27,254	133,156		
Naranja L		222,147		537,801		759,948	1,440,212	Naranja
Verde B	51,368		1,365,054			1,416,422		
Verde C					732,854	732,854		
Verde D			665,870			665,870		
Verde E		191,833	1,186,390	82,516	485,698	1,946,437		
Verde F			227,896	298,984	564,653	1,091,533		
Verde G		401,191			167	401,358		
Verde H				26,986	153,708	180,694		
Verde I		2,268,768	1,943,832			4,212,600		
Verde J					233,275	233,275	10,881,043	Verde
Amarillo C			767,828		297,512	1,065,340		
Amarillo E					5,304	5,304		
Amarillo F				1,822,931		1,822,931		
Amarillo H&K		763,303				763,303	3,656,878	Amarillo
Colorado A			2,547,646	3,054,345		5,601,991		
Colorado C	1,211,910	435,977				1,647,887		
Colorado E				201,678	4,252	205,930		
Colorado F			458,940	645,779		1,104,719		
Colorado H	508,023					508,023		
Colorado K				178,418		178,418		
Colorado R		642,392	48,787	141,754		832,933	10,079,901	Colorado
Merecure	863,393		247,562	524,778	3,172	1,638,905	1,638,905	Merecure
TOTALS	2,634,694	4,925,611	9,689,557	7,723,185	2,723,892	27,696,939	27,696,939	

NOTE: In San Joaquin, when more than one sand is open in one zone the production is arbitrarily split between the sands open.

anism. The pressure pictures are being aided somewhat by the expansion of large initial gas caps updip. There has been little indication of any active water encroachment into any reservoir to date. Recovery factors of 20–30 per cent are currently being used in estimating primary recoverable oil from most of the more important horizons.

PRESSURE MAINTENANCE AND SECONDARY RECOVERY

In an effort to sustain declining reservoir pressures and to utilize some of the gas that is to-day simply being vented to the atmosphere, serious consideration is being given the possibility of installing a compression plant for the return of gas to selected reservoirs. The Naranja "L" sand on the Guario dome is currently being reviewed with such a project in mind. There is plenty of gas available and it would be prudent in many ways to compress, store, and use it wherever possible for the ultimate recovery of more oil.

No definite plans have yet been formulated for the serious exploitation of condensate horizons in this area, but when such exploitation is begun pressure maintenance, cycling operations, or other special procedures will almost surely be included.

OUTLET

As previously mentioned, the oils from the Anaco area fields are pumped to the Anaco station of the Mene Grande's 16-inch pipe-line system leading out to Puerto la Cruz on the Caribbean coast. The Anaco tank farm connected with this station consists of five 96,765-barrel tanks for the receipt of oil being pumped from the Greater Oficina producing area on its way northward to the coast, and for the receipt of Anaco-area oils. These latter oils are kept segregated from Oficina-area crudes, but are themselves mixed and the production from El Roble field is added to make the pipe-line product of the Anaco area known as "San Joaquín Blend."

The Mene Grande pump station at Anaco is equipped with four 6¾-inch by 27-inch Gould triplex double-acting plunger pumps powered by 650-horsepower gas-operated prime movers. Present plans are to install two more large pump units in this station to take the place of some temporary additional smaller pumps and engines now in service. Even now this station is capable of pumping 175,000 barrels of oil per day direct to storage at Puerto la Cruz, 97 kilometers north on the Caribbean coast where the Mene Grande has twenty 96,765-barrel storage tanks in service and has an excellent oil-loading dock with berths for two large tankers. The oil is pumped from this storage up into eight 139,000-barrel floating-roof tanks from which tankers are loaded by gravity feed through two 24-inch loading lines at a rate of about 12,000 barrels per hour per line.

"San Joaquín Blend" from the Anaco-area fields is kept segregated at Puerto la Cruz where it can be blended with oils from other areas if the shipper wishes or it can be exported as "straight wax." Although this oil with its high paraffine wax content does not require any special techniques of handling in the producing fields

or in tank-farm storage in Venezuela, it is usually shipped from Venezuela in tanks equipped with heating coils so that it can be warmed before being pumped out. A pumping temperature of about 95°F. is usually recommended. Almost 26 million barrels of this interesting high-wax crude have been exported to refineries in the United States. The various destinations to which this crude has been shipped from Puerto la Cruz to January 1, 1947, with the percentage by volume shipped to each, are here tabulated.

Destination	*Percentage*
United States	74.8
Aruba, D.W.I.	14.3
Curacao, D.W.I.	9.7
Canada	0.5
France	0.4
Spain	0.2
Brazil	0.1

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 10 (OCTOBER, 1948), PP. 1909-1923, 8 FIGS., 1 TABLE

LITHOFACIES MAPS AND REGIONAL SEDIMENTARY-STRATIGRAPHIC ANALYSIS[1]

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ABSTRACT

Lithofacies maps may be prepared in numerous ways, and this paper emphasizes a statistical approach which brings out the magnitude and rates of change in lithologic characteristics for selected stratigraphic intervals. The interval is divided into percentages of clastics (conglomerate, sandstone, shale) and non-clastics (limestone, dolomite, evaporites), which are combined into a "clastic ratio" and a "sand-shale ratio." The data obtained are numerical and provide a basis for contour-type maps on which the two ratios may be combined to obtain the distribution of statistical lithologic associations. For the more detailed analysis of lithofacies variations a series of ratios based on sandstone, shale, and limestone types is available, which helps differentiate basin, shelf, and geosynclinal deposits. Combinations of lithofacies and isopach maps afford data for interpretations of contemporary tectonics, paleogeography, and to some degree the distribution of environments during the depositional cycle.

INTRODUCTION

The sum total of the lithological characteristics of a sedimentary rock is its lithofacies, and a lithofacies map is an areal representation of sedimentary rock characteristics for a stratigraphic interval. Lithofacies maps are relatively uncommon in the published record, but the earliest forms may be traced back to the beginning of the present century (Grabau, 1932, p. 1145). Gradations of color or degrees of shading are used to show the principal characteristics of the interval, such as its marine or continental nature, or its sandy, shaly, or calcareous facies. In more recent years lithofacies maps have been based on numerical data to show the quantitative variations in the lithologic characteristics. The preparation of lithofacies maps requires a detailed knowledge of the stratigraphic relations of the interval mapped, and the term "regional stratigraphic analysis" has come into general use for this branch of geological study. King's maps of the Permian of West Texas (1942) afford excellent examples.

Most lithofacies maps are based on the dominant lithologic characteristic in the section, but the importance of contrasting the clastic components and non-clastics in the section was early recognized. Ver Wiebe (1930) developed a graphic method for showing this relation by using small circles, which were drawn as whole circles or as arcs on his maps, depending on the relative amount of clastics in the section. Maps based on the percentages of lithologic characteristics carry the idea of numerical representation a step farther, and recently Read and Wood (1947) published a contour-type map based on the ratio of clastic to non-clastic

[1] Paper presented at the Denver meeting of the Society of Economic Paleontologists and Mineralogists, April 29, 1948.

[2] Department of geology, Northwestern University, Evanston, Illinois. The writer is indebted to his colleagues at Northwestern University in the development of the lines of thinking represented by this paper, and to numerous petroleum geologists who have made helpful suggestions and have encouraged the work during its early stages. Among these are A. W. McCoy III of the Phillips Petroleum Company, Ira H. Cram of the Pure Oil Company, and R. T. Hazzard and Charles Ryniker of the Gulf Oil Corporation. The Gulf Oil Corporation has kindly permitted the writer to use certain ideas which were developed originally under their sponsorship.

components in the section. During the past 2 years numerous studies were made at Northwestern University in an attempt to develop methods of general applicability in regional analysis, partly as an outgrowth of the writer's report on "Ancient Sediments" for the A.A.P.G. research committee. (Krumbein, 1947), and partly as a further development of his earlier paper (1945) on contour-type maps of sedimentary attributes. These earlier approaches led to extensions of quantitative facies mapping by the development of various lithological ratios, each of which may be used in particular instances to study the detailed areal variations in lithofacies patterns. Much of the research has been supported by grants from the Graduate School at Northwestern University.

The purpose of this paper is to develop the principles on which the present approach to regional sedimentary-stratigraphic analysis is based, and to show its relation to the background of methodology which precedes it. Examples are drawn from maps prepared at Northwestern University, and these examples are purposely kept rather general to emphasize principles rather than to present detailed maps of intervals or areas.

CLASTIC RATIO AND SAND-SHALE RATIO

A first approximation to the over-all lithological character of a measured outcrop or subsurface section may be had by grouping the rocks into clastics (conglomerate, sandstone, shale) and non-clastics (limestone, dolomite, evaporite) on the usual conventional basis. The thicknesses (or percentages) of clastics are added together and divided by the sum of the thicknesses (or percentages) of the non-clastics. The resulting number is defined as the "clastic ratio."[3] The clastic ratio is augmented by a "sand-shale ratio," which is the ratio of sandstone (plus conglomerate) to shale in the section, regardless of the amount of non-clastics present:

$$\text{Clastic ratio} = \frac{\text{Conglomerate} + \text{Sandstone} + \text{Shale}}{\text{Limestone} + \text{Dolomite} + \text{Evaporite}}$$

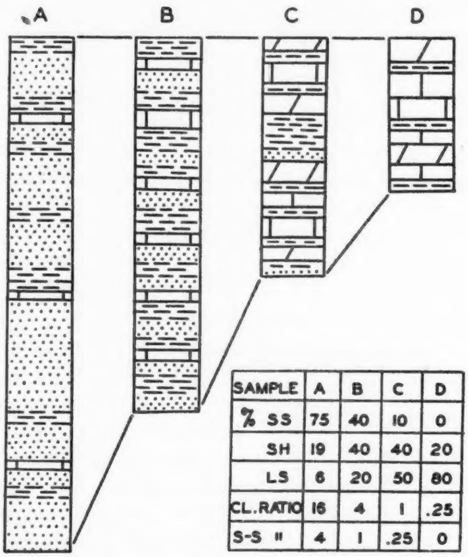
$$\text{Sand-shale ratio} = \frac{\text{Conglomerate} + \text{Sandstone}}{\text{Shale}}$$

These ratios may be readily visualized by considering them as indices of the relative amounts of material in the numerator of the ratio deposited per unit thickness of material in the denominator. A clastic ratio of 2, for example, means that on the average 2 feet of clastic material were deposited per foot of non-clastics, and a sand-shale ratio of $\frac{1}{4}$ means that only $\frac{1}{4}$ foot of sandstone (or conglomerate)

[3] During the early stages of the present study Read and Wood (1947) published a map based on the ratio of clastic to non-clastic components in measured sections and wells. The writer independently defined the clastic ratio at the time the sand-shale ratio and other mapping devices were developed.

accumulated per foot of shale. The ratios apply as averages for the total section considered, and are indices of the gross statistical lithologic associations.

The relation between the clastic ratio and the sand-shale ratio may be seen in Figures 1 and 2. Figure 1 is a hypothetical section from basin to shelf, with a systematic variation in the proportions of sand, shale, and limestone in the section. The percentages of the three components are indicated for each section, as are the clastic ratio and sand-shale ratio. The inset of Figure 2 shows the percentages plotted on a conventional 100-per cent triangle, and the larger triangle



SAMPLE	A	B	C	D
% SS	75	40	10	0
SH	19	40	40	20
LS	6	20	50	80
CL. RATIO	16	4	1	.25
S-S "	4	1	.25	0

FIG. 1.—Hypothetical cross section showing changes in content of sand, shale, and limestone.

is the same figure with the two ratios superimposed on the percentage triangle, and shown as scales along the edges. The clastic ratio plots as horizontal lines, with zero at the top, and infinity at the bottom. The sand-shale ratio plots as a series of lines converging toward the non-clastic apex, with infinity at the left and zero at the right. The four points of the percentage triangle fall at the corresponding positions of the two ratios in the larger triangle. In terms of the cross section of Figure 1, the lithologic character changes from a section composed mainly of sandstones, through a section of sand, shale, and limestone, to one composed dominantly of shale and limestone.

There is a fixed relation between the clastic ratio and lithologic percentages, as Figure 2 shows. This relation may be illustrated by Table I, which indicates the percentages of clastics and non-clastics for selected values of the clastic ratio.

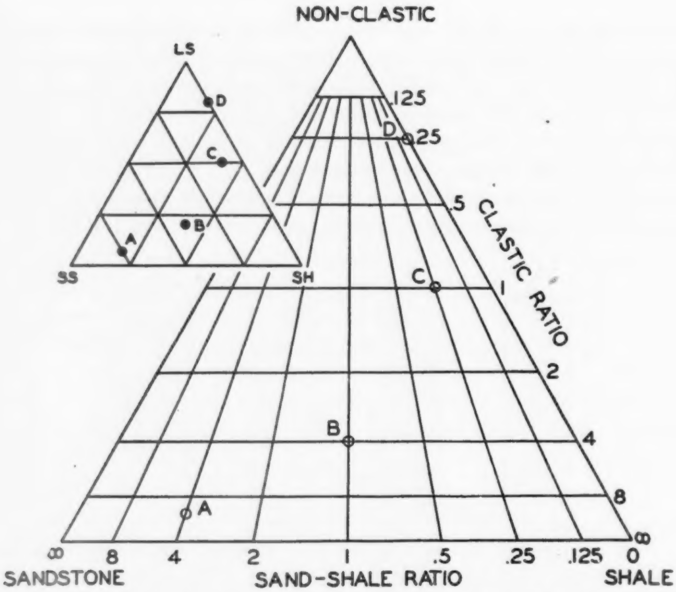


FIG. 2.—Lithofacies triangle, showing relation of clastic ratio and sand-shale ratio to conventional 100-per cent triangle (inset). Points on triangles refer to data of Figure 1.

The large numerical range of the ratios renders it convenient to use geometric intervals in preparing maps. The interval thickness and the two ratios are plotted at the control points, and isopachs are drawn over the area. The first lithofacies line drawn on the map is the clastic ratio value 1.0, which represents the balance between clastics and non-clastics. Geometrical intervals are then selected on the

TABLE I

Clastic Ratio	*Percentage of Clastics*	*Percentage of Non-Clastics*
∞	100.0	0.0
32	97.0	3.0
16	94.1	5.9
8	88.9	11.1
4	80.0	20.0
2	66.7	33.3
1	50.0	50.0
$\frac{1}{2}$	33.3	66.7
$\frac{1}{4}$	20.0	80.0
$\frac{1}{8}$	11.1	88.9
$\frac{1}{16}$	5.9	94.1
$\frac{1}{32}$	3.0	97.0
0	0.0	100.0

basis of the range of values shown by the control points, and on the detail in which the facies are to be indicated. In similar manner the sand-shale ratio is contoured to indicate the changing proportions of coarse and fine clastics over the area. The final map has three sets of contours, which can be recognized by line pattern or by coloring certain intervals which are to be emphasized. More generally, the two ratios may be combined into a set of statistical lithologic differentiations as suggested in the following paragraph.

M. King Hubbert[4] has suggested the use of logarithms of the ratios to reduce the range of the numerical data. Logs to any base would have a "zero contour" along the ratio value of 1.0, with positive numbers for increasing values, and negative numbers for fractions. Logs to the base 2 for the clastic ratios in Table I would yield a range from 5 for 32 to -5 for $1/32$. In similar manner, the sand-shale ratio may be contoured logarithmically.

An example of lithofacies maps is given in Figure 3. It is adapted from a Cambrian map prepared by Sloss (1948), and the upper map shows generalized isopachs, clastic ratio lines, and sand-shale ratio lines. The three sets of lines render the map somewhat cumbersome, and in practice the clastic ratio may be used alone with the isopachs, if the section shows a balance between clastics and non-clastics. On the other hand, in dominantly clastic sections the sand-shale ratio may be used alone (Dapples, 1948).

The lower map of Figure 3 is a combination of the clastic and sand-shale ratios in the upper map, and it shows the statistical lithologic differentiations of the map area. The map is based on combinations of the clastic ratio and the sand-shale ratio in terms of certain limiting values. For example, in Figure 2 the area on the larger triangle bounded by a clastic ratio of 8 and a sand-shale ratio of 8 defines a lithologic association composed of about 90 per cent sandstone on the average; and a similar section bounded by a clastic ratio of 8 and a sand-shale ratio of $\frac{1}{8}$ bounds an area composed of about 90 per cent of shale on the average. In like manner, if the clastic ratio is less than $\frac{1}{8}$, regardless of the value of the sand-shale ratio, the section contains more than about 90 per cent non-clastics. The remainder of the triangle may be divided into additional areas to obtain a group of statistical lithologic associations. Figure 4 shows examples of nine generalized statistical lithologic groups associated with certain areas of the triangle (shown in perspective), to show the systematic variations of the statistical groups. In practice, each statistical lithologic group is colored with variations of yellow, green, or blue, according to the prevalence of sand, shale, or limestone in the lithologic groups.

The lower map of Figure 3 is based on the limiting values of Figure 4, and for clarity only these limiting contours are drawn on the upper map. In practice both ratios are usually contoured on intervals which differ by a constant factor of 2, as $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, *et cetera*.

[4] Personal communication.

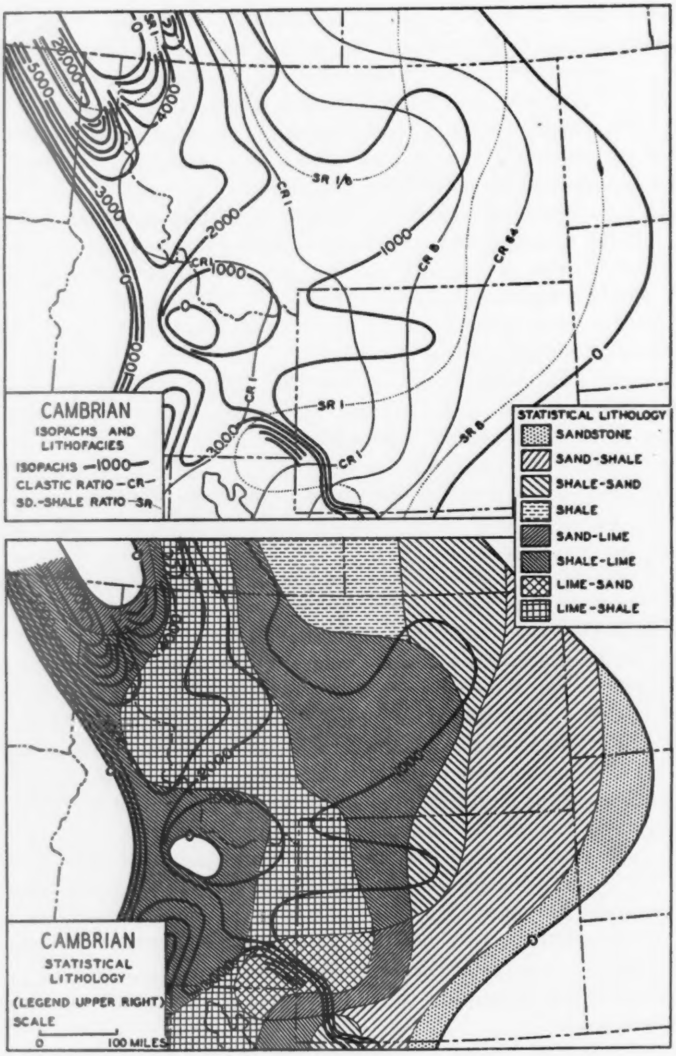


FIG. 3.—Cambrian isopach and lithofacies maps, after L. L. Sloss. Post-Laramide erosion reconstructed; geosynclinal isopachs generalized.

For convenience in naming the statistical lithologic groups, the dominant rock name may be placed first, followed by the next most dominant in the intermediate groups. In terms of Figure 4, the limiting groups are limestone, sand-

stone, and shale sections. The two classes between clastic ratio $\frac{1}{8}$ and 1 are limestone-sand and limestone-shale sections. The more clastic intermediate groups are sand-limestone and shale-limestone sections; and the remaining two groups between the sandstone and shale are sand-shale sections and shale-sand sections, respectively.

The statistical lithologic groups in Figure 3 show that the Cambrian section changes from an area of dominant sandstone (clastic ratio and sand-shale ratio both greater than 8) westward through sections of increasing shale content (clastic ratio greater than 8, but sand-shale ratio decreasing to less than 1), to a section of dominant shale with some limestone (clastic ratio between 8 and 1; sand-shale ratio less than 1), and finally into an area of dominant limestone with subordinate shale (clastic ratio and sand-shale ratio both less than 1). In the southern part of the map area the sandstone section appears to grade into a sand

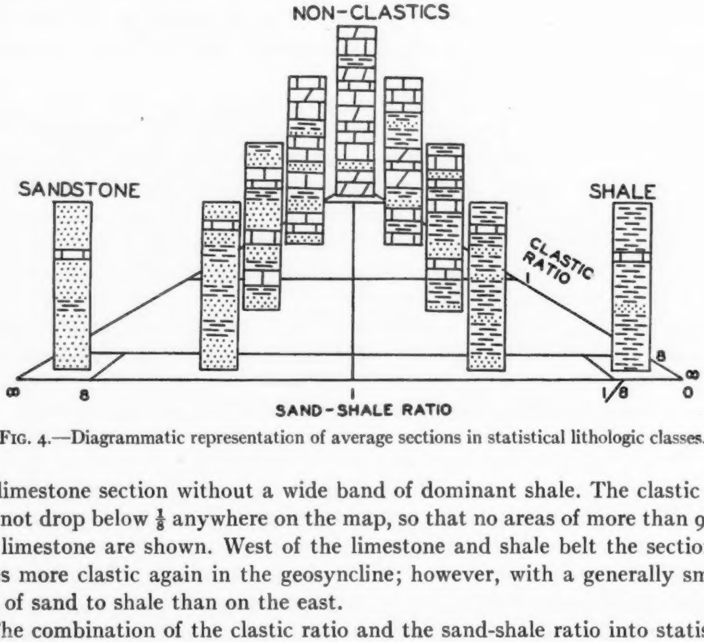


FIG. 4.—Diagrammatic representation of average sections in statistical lithologic classes.

and limestone section without a wide band of dominant shale. The clastic ratio does not drop below $\frac{1}{8}$ anywhere on the map, so that no areas of more than 90 per cent limestone are shown. West of the limestone and shale belt the section becomes more clastic again in the geosyncline; however, with a generally smaller ratio of sand to shale than on the east.

The combination of the clastic ratio and the sand-shale ratio into statistical lithologic groups affords a simple map of the main lithologic character of the whole section. The maps may be further simplified or complicated by different choices of limiting ratio values; and to some degree the selection of limits may be controlled by the thickness of the interval being measured and the particular details which are to be emphasized.

Both the clastic ratio and the sand-shale ratio were designed as rapid means

for expressing gross lithofacies on maps. For this purpose the clastics are defined as rocks having more than 50 per cent of detrital components (rock fragments, sand grains, clay particles), and the non-clastics contain more than 50 per cent of chemical components (carbonates, sulphates, phosphates, *et cetera*). Limestones with clastic textures are included with the non-clastics, although in special instances it may be desirable to recast the definition to bring in the specific influence of clastic limestones, diatomaceous shales, and the like. In its present form, however, the clastic ratio is based on conventional lithologic classification.

Abundant conventional data in the form of cutting logs are available in publications and at State geological surveys for regional maps on the larger intervals; and for industrial research the data are even more abundant. The writer uses base maps on a scale of 1:2,500,000 for regional studies involving several states. Data are assembled on a control involving one well per county in the middle western states, if that many are available. In the areas of sparse control drillers' logs may have to be used, inasmuch as they are fairly reliable on interval thicknesses, if not on the gross lithologic character. Such logs, however, are omitted where other control is available.

The base map for lithofacies variation is an isopach map. The writer prefers to draw the isopachs with as little interpretation as possible regarding former extent of seas. That is, the zero isopach is the present limit of the interval. Local absences due to known erosional intervals are important in detailed studies, but may be ignored in broader regional analyses. The resulting factual picture provides a basis for reconstruction of the paleogeography in terms of the changing clastic or non-clastic nature of the sediments as they are followed toward the zero contour. Where the lithofacies lines run abruptly into the zero isopach the suggestion is strong that the original shore line does not correspond with the present zero isopach. Where isopachs and lithofacies lines are parallel, the original shore line may in some instances be placed rather satisfactorily. Criteria for erosional versus depositional edges will be discussed in a later publication.

RATIOS OF LITHOLOGIC SUBTYPES

The next higher level of lithofacies analysis involves a detailed examination of the specific types of rocks present in the section. Sandstones, shales, and limestones occur in wide variety (Dapples, 1947; Krumbein, 1947; Sloss, 1947), and an analysis of the subtypes present affords data for more critical examination of the lithofacies pattern. This level of analysis may be approached by considering rocks which fall within one or another of the apices of the triangle of Figure 2. The non-clastic apex, for example, may itself be considered as a triangle having various components, such as relative proportions of unaltered limestone, secondary dolomite, and secondary chert in the section. A limestone alteration ratio may be developed by dividing the total thickness of beds of unaltered limestone in the section by the sum of the thickness of dolomitized cherty beds, as indicated in the upper left-hand triangle of Figure 5. The dolomite-chert ratio along the

base of the triangle provides a basis for expressing the relative amounts of these two components in the section.

Another approach to the analysis of limestone sections associated with evaporites is to contrast the relative amounts of carbonate, sulphate, and chloride in the section, as shown in the upper right-hand triangle of Figure 5. An evaporite ratio may be defined as the ratio of the sum of the thicknesses of sulphates and chlorides in the section divided by the thickness of carbonates in the section. A sulphate-chloride ratio along the base of the triangle may also give some information on the variation of evaporite components.

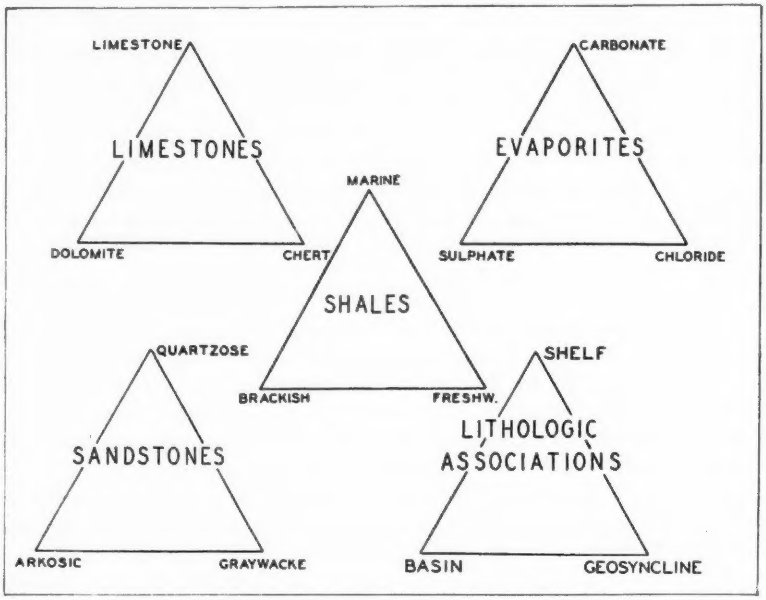


FIG. 5.—Triangle diagrams illustrating lithologic associations which may be used as basis for lithofacies ratios.

An example of limestone analysis is afforded by the somewhat generalized map of Figure 6, which shows the ratio of cherty limestone to total limestone in the Meramec of western Kansas and eastern Colorado. The influence of the central Kansas uplift is brought out, as is the general spotty nature of the alteration pattern on the thinner shelf areas.

Sandstone types lend themselves readily to detailed analysis. The occurrence of quartzose sandstones, arkoses, and graywackes affords data on the tectonic controls of sedimentation (Krynine, 1945, 1948; Dapples, 1947). Quartzose sandstone typically occurs on stable shelf areas and represents tectonic stability,

whereas graywackes are indicative of strong negative conditions in the depositional area. Arkoses are special sandstones associated apparently with marked orogenic disturbances and rapid accumulation. By setting the three sandstone types at apices of a triangle as shown in Figure 5, lower left, it is possible to define an inferred tectonic stability ratio by dividing the thickness of the quartzose sandstone by the combined thicknesses of arkose and graywacke. In this type of analysis the vertical variability of the section must be taken into account, inasmuch as it is relatively rare to have extreme types closely associated in any section. However, quartzose sandstones are known to occur in dominant graywacke sections, and they may indicate times of relative tectonic stability even in such mobile belts.

It is possible to define shale types in terms of their composition and texture (Krynine, 1945; Krumbein, 1947), and to establish ratios similar to the sandstone ratios, but the shales may lend themselves more to an evaluation of average environmental conditions. A triangle contrasting marine, brackish-water, and fresh-water shales (center, Fig. 5) provides a basis for a marine shale ratio obtained by dividing the thickness of the marine shales by the combined thickness of brackish and continental shales. A supplementary ratio could then be based on the ratio of brackish to continental shales, to find transitional shore zones.

LITHOLOGIC ASSOCIATION RATIOS

Contemporary studies of lithologic associations (Krynine, 1947; Dapples, Krumbein, and Sloss, 1948) suggest that particular combinations of sandstones, shales, and limestones are associated with tectonic stability and with varying degrees of tectonic instability. By evaluating the measured sections in terms of the proportions of such associations, it appears possible to map areas of statistical lithologic groups which carry with them certain implications of the tectonic framework in which the sedimentation occurred. For example, associations of quartzose sandstones, clay shales, and normal fragmental marine limestones are indications of relatively stable shelf conditions, whereas the occurrence of subgraywacke sands, coarse silty shales, and nodular limestones suggests increasing contemporaneous tectonism; until finally the association of graywackes, black silty shales, and minor siliceous limestones suggests strong geosynclinal conditions.[5] The dominant associations may be plotted on a triangle diagram of the type shown in Figure 5, lower right, to obtain shelf, basin, and geosynclinal groups of associated lithologic characteristics. From such a map it may be possible to reconstruct the areas of relative stability or instability during the time of deposition. Figure 7 is an experimental map of this type, much generalized, but illustrative of the principles involved. The interval represented is the Missouri-Des Moines series. The map shows the present limit of the series, and the isopachs are generalized on a 500-foot interval. The pattern of associated lithologic characteristics shows a broad central region of dominant shelf-limestone associ-

[5] These statements are oversimplified. See Dapples, Krumbein, and Sloss (1948) for details.

ations (clastic ratio less than 1.0) in Kansas, western Nebraska, and northeastern Colorado. West of this area, across a narrow transition zone apparently of shales, is a dominant arkosic sandstone association along the present Front Range. Northward, in Wyoming, western North Dakota, and Montana, is a dominant quartzose sandstone association, with some local shelf limestone dominance. Intercalated with both the quartzose sandstone and dominant shelf limestone associations of eastern Wyoming and western North Dakota is an evaporite basin, and lying northward and eastward of the shelf limestone association is a sand-

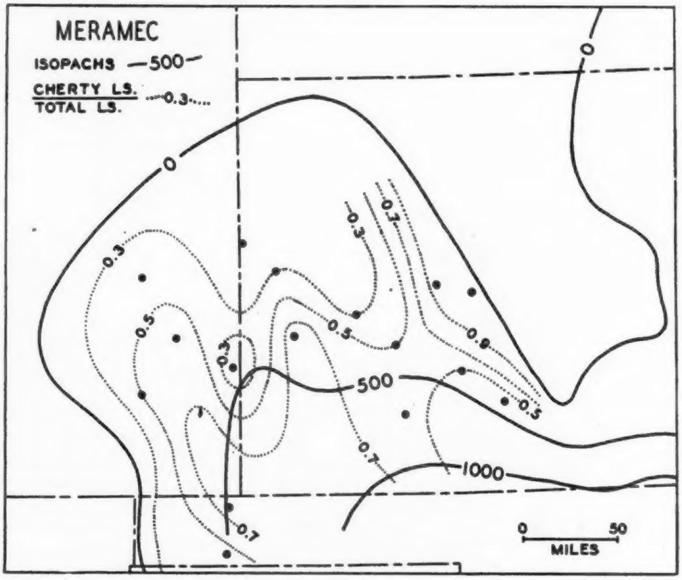


FIG. 6.—Generalized map of ratio of cherty limestone beds to total limestone in Meramec. Data from published sources.

shale section with a sand-shale ratio less than 1.0, and a clastic ratio greater than 1.0. This sand-shale section has silty shales, subgraywacke sands, and in its eastern part at least, through Iowa, Missouri, and Kansas, contains coal cyclothems. Marine limestones are generally thin and commonly nodular.[6]

The implications of these lithofacies associations is that during Missouri-Des Moines time, on the average, the depositional area (which in all likelihood covered the whole map except for the Ancestral Rockies) showed different degrees of contemporaneous tectonic activity. The shelf limestone association and the

[6] The transition between the arkose and the limestone in eastern Colorado is shown in the same pattern as the large subgraywacke area. However, the sands in the smaller area apparently are more quartzose, rather than micaceous.

quartzose sand association suggest maximum stability, whereas the sand-shale area on the east, with its alternation of coals and thin marine limestones, implies mild oscillation above and below sea-level. The strong arkose association along the Front Range, with its great thickness of sediments, indicates strong tectonic influences, negative in the basin, and positive in the bordering Ancestral Rockies. The basinward thickening of individual members of the Missouri-Des Moines

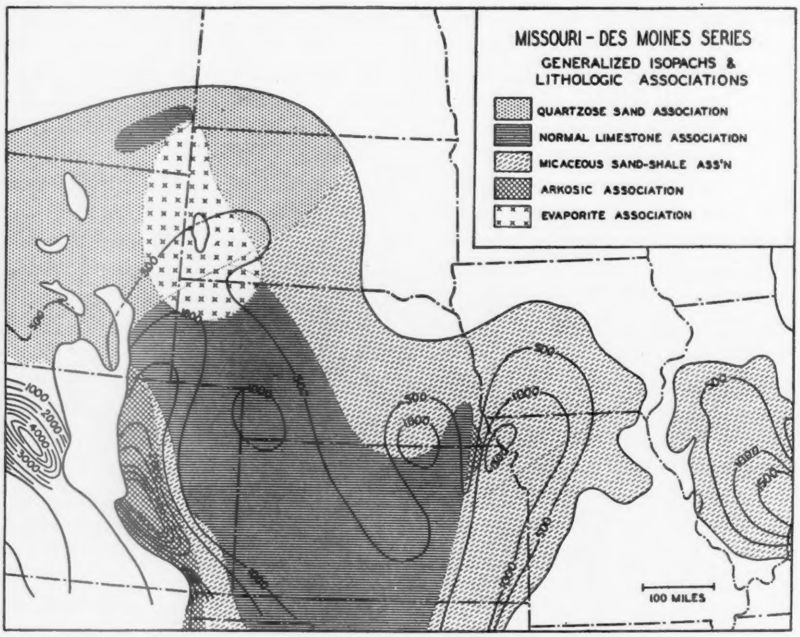


FIG. 7.—Experimental map showing lithologic associations in Missouri-Des Moines series.

toward the Forest City and Illinois basins suggests contemporaneous moderately negative movements. The buried Nemaha ridge, which locally poured arkose into the Cherokee of the Forest City basin, showed some local positive tendencies during at least part of the interval.

This broad tectonic interpretation can be shown on a map by using a scale of relative tectonism from stability to maximum positive or negative tectonics. In the legend of Figure 8 stability is shown by blank areas, and mild oscillations are horizontally ruled. If the oscillations tend mainly toward negative tendencies, a coarse cross-hatching is used, and more definite negative tendencies are indicated by closer cross-hatching. The strongest tectonic movements are indicated by dark ruling for negative movements, and black for strong positive tendencies.

The map of Figure 8 is an attempt to indicate the contemporaneous tectonic framework of the Missouri-Des Moines with such a sliding scale. The shelf limestone and quartzose sandstone areas are left blank to indicate stability, with a very mild negative tendency in the evaporite basin. Mild positive and negative oscillations occurred in the micaceous sand-shale area, and moderate negative tendencies occurred in the Forest City and Illinois basins. The Nemaha ridge locally had positive tendencies in its northern part. The areas of strongest positive and negative tendencies occurred in the Ancestral Rockies and adjoining arkose basin.

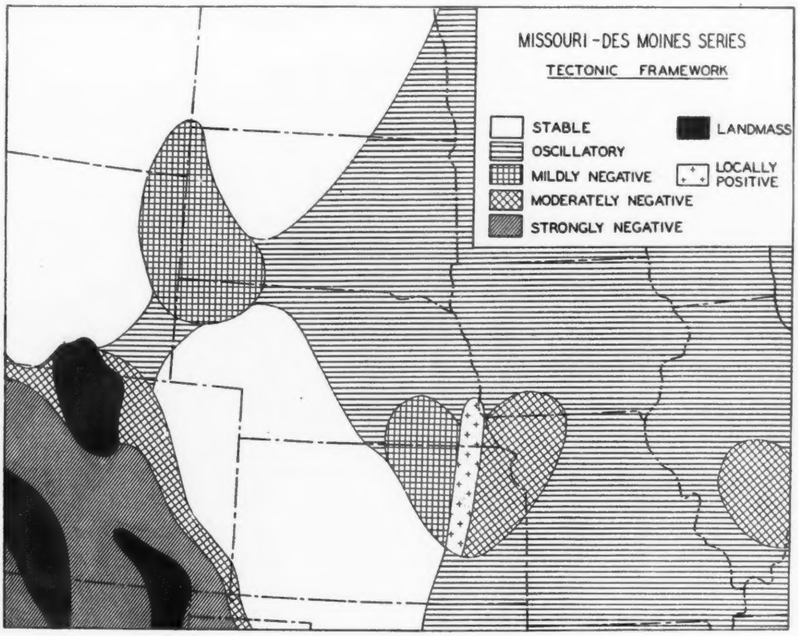


FIG. 8.—Experimental map of average contemporary tectonic framework of Missouri-Des Moines series.

The tectonic framework map is frankly experimental, and is included mainly to direct attention to the possibilities of using lithofacies associations and isopachs for the reconstruction of degrees of contemporaneous tectonism. In strict usage the isopachs should be used for interpretation only where they are preserved under a Douglas group cover, and in practice it may be found that the interval used for illustration may be too thick for detailed analysis, inasmuch as some areas changed their tectonic behavior during the interval. The Nemaha ridge, for example, appears to have been active during the Cherokee, but it remained relatively quiescent from the Marmaton on. Similarly, the Central Kan-

sas uplift was a low epeirogenic positive mass in the early part of the interval, but remained stable thereafter. Apparently some tectonic variation occurred also in a belt extending diagonally across South Dakota to southeastern Wyoming, as indicated by the red continental-like shales associated with the section. These complexities may become less important with the study of thinner intervals, but there still remains the question of appropriate methods for indicating average or dominant tectonics during the longer intervals of geologic time.

ENVIRONMENTS OF DEPOSITION

There is little doubt that the broad pattern of contemporary tectonics controls the equally broad pattern of environmental zones, inasmuch as tectonics largely controls the distribution of land and sea; hence, the distribution of continental, littoral, and neritic zones. The environment in turn controls the patterns of sediment distribution, and their biologic associations, but the rate of sedimentation may influence the length of time during which a set of environmental factors may operate on its material. The complete interpretation of contemporary tectonics must therefore include not only the lithologic associations and isopachs, but also the broad environmental patterns and the role of the source area in terms at least of distance and rate of supply.

The question of environments of sedimentation has not been touched upon explicitly in this paper. This is not due to its lack of importance, but to the relatively greater complexity of environmental interpretation. Shifting strand lines and alternations of marine and continental beds make difficult the problem of reconstructing an average environment for a given interval. What is the average environment for a cyclothem, which may contain continental sandstone, fresh-water limestone, marine limestones and shale, and coal?

One approach to the environmental problem may be had by contrasting types of shale as suggested in the shale triangle of Figure 5. Contours on marine-non-marine facies may suggest the areas of rapid or slow transition from dominantly marine to continental conditions. Similar ratios of types or abundance of fossils, as muddy-water inhabitants to clear-water inhabitants, may also help differentiate environmental zones or patterns.

It is the writer's belief that the effectiveness of environmental maps is increased by numerical data which permit the construction of contour-type maps. In the absence of numerical data, however, broad environmental pattern maps may be prepared by indicating littoral and neritic zones in the marine facies; and continental, brackish, or alternating marine-non-marine zones along the sea margin. Despite changing conditions during any geologic interval, it may be possible to indicate an average environmental condition, or the dominant environmental condition. To the extent that the environmental pattern map includes faunal and floral assemblages, as well as conventional criteria of water depth or agitation (ripplemark, crossbedding, *et cetera*), it becomes a valuable supplementary tool for interpretation of the rock column. In an earlier paper (1947) the writer ex-

pressed the belief that at least three fundamental approaches are involved in the interpretation of the rock column. These are studies of the tectonic framework of sedimentation, the tectonic intensity, and the influence of the depositional environment (Kay, 1947; Krumbein, 1945; Krynine, 1943, 1948; Pettijohn, 1943; Umbgrove, 1947). The relative importance of these parallel approaches to the larger problem will be determined as knowledge accumulates, but it seems safe to predict that none of them can be ignored.

CONCLUDING REMARKS

The implications of lithofacies mapping extend in several directions toward integrations with broad environmental studies, with analyses of contemporaneous tectonics, with the reconstruction of paleogeographic conditions, and with the occurrence of oil. Geology has been able to expand its frontiers with the wealth of subsurface data made available by oil exploration, and published through the courtesy of oil companies. A major problem in handling this wealth of information is the development of techniques which aid in organizing and interpreting the data. Logical extensions of methodology include maps based on more detailed and critical analyses of lithofacies, and especially their integration with analyses of the biofacies. The degree to which lithofacies and isopachs reflect contemporary tectonics requires additional study, and there is need for sharpened methods of interpreting the associated depositional environments.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 10 (OCTOBER, 1948), PP. 1924-1947, 4 FIGS. 1 TABLE

TECTONIC CONTROL OF LITHOLOGIC ASSOCIATIONS[1]

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ABSTRACT

Lithologic responses to tectonic controls permit the organization of sediments into several broad groups, depending on their accumulation on shelves, in basins, or in geosynclines. Each lithologic association includes particular sandstones, shales, and limestones, which in the aggregate are the result of the tectonic framework, the tectonic intensity, and the nature of the depositional environment. The writers point out typical lithologic associations, and attempt to organize the criteria by which they may be recognized. Examples are given from regional studies, and a tabular summary is presented of associated rock types set within their tectonic framework.

INTRODUCTION

Lithologic repetition in a stratigraphic interval is common through much of the geologic column. The cyclical repetition of beds in the coal cyclothems of the central states is a familiar example. Certain lithologic types appear to have affinities with one another, such as underclays with coal, green shales with quartzose sandstones, and evaporites with dolomites. Such affinities are too common to be vagaries of sedimentary accumulation; hence, they are recognized as lithologic associations within a framework of deposition. These repeated associations are implied when a section is referred to as a typical shelf facies, or a continental facies, or a geosynclinal facies; they connote the development of certain lithologic types within limited conditions of accumulation. The concept of rock facies implies that when a source area delivers a unique type of débris to a depositional basin, a special type of rock is produced as a result of the integration of the source and the depositional environment. It also implies that when the same combination occurs in another locality or at a later geologic time, a similar deposit results. The concept places equal importance on the source and depositional conditions, but, in general, conditions in the depositional area are of greater importance than those in the source area in developing the lithologic character of the resulting sedimentary rock. In the area of sedimentation a major factor which controls the type of sediment is the tectonic behavior of the area, because this controls the distribution of sedimentary environments through a control of the strand line. The tectonic behavior can be considered in terms of the degree of negativeness or stability of the depositional area. Where the depositional area is prevailingly stable the conditions of a shelf[3] are established; where the depositional area becomes increasingly negative toward a center, an intracratonic basin is formed; and where the depositional area becomes strongly

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[2] Department of geology, Northwestern University. The writers are indebted to the Graduate School, Northwestern University, for support of this research.

[3] The writers previously used the term "platform" to designate essentially stable depositional areas. At the suggestion of others the term "shelf" is used instead.

negative along a lineal mobile belt, a geosynclinal condition is established. In each of these tectonic depositional areas a pattern of environmental factors persists, the length of time depending on the tectonic intensity, rates of sedimentation, and other factors. In each tectono-environmental complex an association is developed of sandstones, shales, and limestones which have diagnostic mineralogic, textural, and structural features.

The writers believe that the tectonic behavior of the depositional area is the most important factor in the control of lithofacies, and that the environment of deposition (littoral, neritic, *et cetera*) plays a part which depends on the length of time environmental conditions can affect the material before it is buried. The source area, except in special instances, appears to be a less important factor. The tectonic behavior of the depositional area itself includes several factors, among which are the geographic distribution of tectonic elements, and the intensity of the tectonism in each.

It is the writers' purpose to discuss the tectonic aspects of lithologic associations by pointing out common associations and by attempting to organize the criteria by which they may be recognized and interpreted. In later papers the writers hope to develop further the elements of tectonism and to superimpose upon the tectonics and the lithologic associations the broad patterns of environmental control.

In previous publications (1947) the writers described sandstones, shales, and limestones; and each was shown to have characteristics associated with shelf, basin, or geosynclinal deposition. Where the thickness of strata in a time-stratigraphic unit shows numerous and marked changes, the associated sandstones, shales, and limestones show changes in character with the development of new facies. In part the present discussion is directed toward expanding the concepts already presented, and exploring further a field which appears to offer interesting possibilities for understanding the nature of sedimentary accumulation.

SHELF

CONDITIONS ON STABLE SHELVES

Shelf areas appear to cover considerably larger areas geographically than either the intracratonic basin or the geosyncline. They suggest regions such as the present Atlantic coastal plain where the shore line represents a boundary between aqueous and subaerial conditions but where the general profile of the land surface continues beneath the water with only slight modification. The shore line may be embayed as in the northern half, or it may be nearly straight as in Florida. The essential condition required, however, is that throughout the period of its existence, tectonic stability prevails in the depositional area of the shelf and extends into the source area for some distance.

Along such a coast line, wave action may be uniform, with quiet days seasonally restricted so that material furnished by the entering streams accumulates along the shore. During stormy seasons the waves have sufficient energy to

establish strong currents which shift the débris along the shore and seaward. The supply of sedimentary material is small in comparison with the area of the shelf; consequently, there is continual shift of material from place to place without permanent burial.

In contrast to these conditions of turbulence and relatively high energy dissipation, the stable shelf area may have broad expanses of quiescent waters; or there may be alternations of these conditions. Thus one may conclude that the coarser shelf sediments are associated with the more turbulent conditions; whereas, the finer-grained sediments may represent quiescent phases. The winnowing process in the more turbulent areas segregates the light particles from the coarser and heavier. The light particles move basinward or into embayed parts of the shore line where more quiescent conditions prevail. During the winnowing process several characteristic features are developed in the sediments. Material furnished to the shore may have a variety of minerals, but the more unstable minerals apparently are reduced in amount during resting or shifting in the subaerial, littoral, or neritic zones, inasmuch as the major part of the land-derived sand which finally accumulates on the shelf consists of quartz and a small percentage of very stable minerals.

In areas of greatly reduced wave action or during relatively quiescent times, glauconite may form. Where fine-grained detritus has accumulated, the glauconite apparently imparts a green color to clay shales, commonly associated with quartzose sandstone. The glauconite grains preserved in more sandy areas may have been swept in during times of greater turbulence and well distributed over the shelf.

Large-scale cross lamination of the torrential type, showing marked unconformable relationships, occurs in typical quartzose sandstones, such as the Lyons formation in its type locality, and the Cambrian sandstone in the Dells of the Wisconsin River. The writers interpret these as local concentrations of detritus preserved on the shelf rather than as great floods of material furnished from a landmass. To the writers, one of the prime requisites of stable shelf conditions, in the more turbulent areas at least, is that the supply of sedimentary material be small so that for a relatively long time the débris has only temporary resting places and is repeatedly reworked until it is finally buried.

The constant reworking of the sedimentary material in the more turbulent zones develops the high degree of sorting typically found in the best examples of shelf-type sandstones. Figure 1 (adapted from Dapples, 1948) is a map of the St. Peter sandstone over a large area in the central states. The dotted lines of equal sorting show a high degree of sorting (small values of phi sigma) over the area. A smaller contour interval would reveal randomly distributed local deviations from the generally uniform north-to-south increase in degree of sorting. Such local variations within the body of the St. Peter even at one locality have been demonstrated by Thiel (1935), along the outcrop in Minnesota and Wisconsin. The local variations are probably the result of local current conditions in the

over-all current pattern which shifts fine débris basinward. Hence, the percentage of shale in the sand may also be expected to respond to these local current variations, and as the sand-shale pattern of Figure 1 shows, there are local areas of high shale content also apparently randomly distributed. The smallest shale

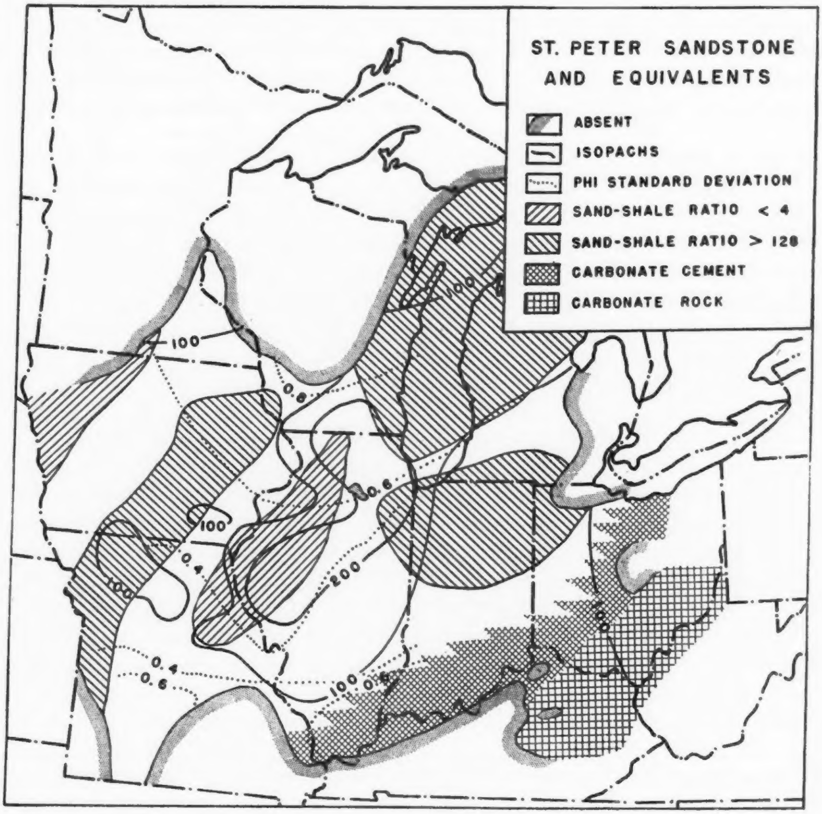

FIG. 1.—Areal distribution of St. Peter sandstone and time-stratigraphic equivalents in central states, showing thickness, sand-shale ratio, degree of sorting, and areas of carbonate cementation and carbonate rock. (Adapted from Dapples, 1948.)

percentages are at the north edge of the sand sheet, and higher shale percentages appear in part to be related to areas of greatest St. Peter thickness. However, the relation of lithofacies to isopachs may locally be modified by deposition on irregular slope, or by local post-depositional erosion.

Some areas of the shelf become regions of dominant carbonate deposition. In some places these appear to be little different tectonically or dynamically from

the zones of active sand deposition. In Figure 1, the eastern margin of St. Peter sandstone occurrence is marked by the appearance of carbonate cement in the sandstone, rather than the silica cement which is prevalent on the north and west; and beyond the limits of carbonate cementation the equivalent section consists of carbonate rock. The carbonates contain insoluble residues marked by the presence of quartz grains of rather high sphericity, commonly frosted and pitted, or showing quartz enlargement. Silt of the same material may also compose a prominent part of the residue. A change from quartzose sand deposition directly to carbonate deposition is common on stable shelves. In addition to the St.

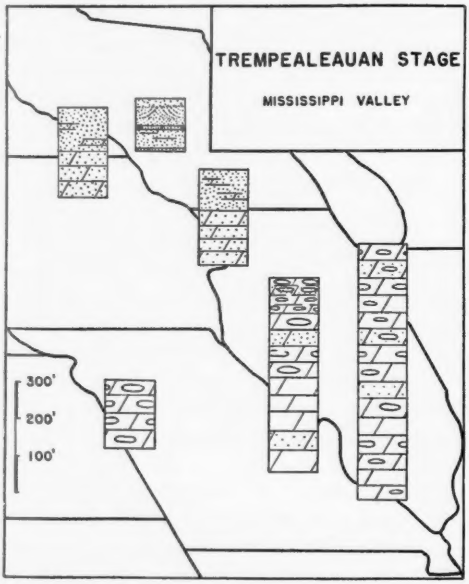

FIG. 2.—Representative sections of uppermost Cambrian strata in Mississippi Valley, illustrating gradation of time-stratigraphic unit from sandstone to dolomite in stable shelf environment.

Peter, the Upper Cambrian from Wisconsin to Missouri, and the Tensleep and its equivalents in Montana, illustrate the direct transition from sandstone to limestone. Figure 2 shows several sections of the Trempealeau and equivalents (uppermost Cambrian) from Wisconsin to Missouri, illustrating the change from sandstone to limestone without an intervening shaly facies. The southward thickening suggests a transition toward basin conditions.

Deposition on a stable shelf represents transgressive and regressive phases. Unconformities are common at the base of the sandstone units and definite transgression of time lines is expected. This shifting carries the littoral zone over the shelf area and endows much of the section with typical shore-line characteristics.

Should broad dune belts develop along the coast line, parts of these may be preserved and in consequence intermingle eolian deposition with marine phases. As examples, the Nugget, St. Peter, and Coconino sandstones have been considered in part to represent deposits in eolian environments.

BIOLOGIC ATTRIBUTES OF STABLE SHELF

Under the conditions of slow sediment accumulation prevailing on a stable shelf, bottom-dwelling organisms may be expected to have an important influence on the products of sedimentation. From physical evidence it is apparent that most of the shelf deposits have been formed in the shallow waters of the littoral and neritic zones, where the greatest abundance of benthonic forms occurs. Solar energy of the proper wave lengths is able to penetrate to the bottom over large areas, promoting the growth and proliferation of a rich, algal flora. The algae support directly or indirectly a great many and various nektonic and benthonic forms. Many of the latter are capable of contributing directly to sedimentation by the precipitation of carbonates; whereas the scavengers, in their ceaseless plowing of the bottom muds and sands and in their habit of passing sediments through their digestive tracts, are able profoundly to alter the nature of shelf sediments prior to lithification (Dapples, 1942; Twenhofel, 1942; ZoBell, 1942).

Shelf sands are naturally poor in fossils, but this does not necessarily imply deposition under aseptic conditions devoid of life. Present areas of sand accumulation are fairly well populated particularly by scavenging annelids and echinoderms plus numerous forms which might normally be expected to be preserved as fossils. The dynamics of the turbulent parts of the shelf environment responsible for the constant reworking of the sands are also responsible for the gradual abrasion, attrition, and nearly inevitable elimination of organic remains.

Areas of accumulation of detrital materials of fine silt and clay sizes may offer optimum conditions for a rich and diverse biota. Indigenous micro-organisms plus organic débris swept in from other areas provide an abundant fare for a host of animal types including great numbers of mud-eating scavengers. Moreover, tests of such planktonic forms as diatoms and smaller foraminifera are preserved as important contributions to the sedimentation. Under special conditions of more rapid mud accumulation, the accompanying turbidity inhibits the normal development of the fauna and flora and relatively non-fossiliferous shales may result.

Areas of carbonate accumulation represent marine areas devoid of significant quantities of land-derived detritus in transport. Both planktonic and benthonic forms are important contributors to sedimentation, in some places one, in some places the other, being predominant. Clear shallow seas rich in phytoplankton support a varied biota of sessile benthonic forms such as pelmatozoans, corals, bryozoans, oysters, brachiopods, lime-secreting algae, and numerous vagrant echinoids, and the larger foraminifera. As the solitary sessile types such as

crinoids die, their calcareous parts are dissociated and distributed to their final resting places as clastic particles by waves and currents. Upon the mortal remains of the past, new generations find places of attachment, complete their life cycles, and contribute their remains to a growing accumulation of fragmental limestone. Colonial types continue to grow as sedimentation proceeds and in special cases may achieve the ecologic conditions resulting in bioherms.

Carbonate deposition on the shelf is not to be interpreted as restricted to regions distant from the shore. Carbonate rocks will presumably develop wherever the clastic load is insufficient to mask the carbonate which is accumulating. Moore (1929) suggests that some Pennsylvanian limestones formed practically to the shore line, and a similar phenomenon occurs to-day in the Great Australian reef and the east coast of Florida. On the other hand, carbonates may accumulate some distance from the mainland, as in the Bahamas. Apparently no restrictions can be placed on carbonate deposition of the shelf type with respect to distance from shore. It is possible that true near-shore phases of carbonate accumulation may carry with them some diagnostic features by which they may be identified.

DEPOSITS ON STABLE SHELVES

When a shelf remains stable the accumulation of sediments is limited to a thin sequence of continental or marine deposits of only a few hundred feet. The accumulation of even a thin sheet of sediment implies that a stable shelf is subject to a very slow rate of sinking during deposition. However, it appears paramount that the rate of this sinking and the rate of sedimentation be in such balance that littoral and neritic conditions operate on the material long enough to impress their environmental characters on the deposits. When such conditions prevail, particular types of sandstones, shales, and limestones are associated, and are herein called the stable shelf association.

Sandstones.—Stable shelf sands all dominated by an abundance of quartz can be grouped into four general types, namely, pure quartz, quartz-glauconite, quartz-iron oxide, and quartz-muscovite (Dapples, 1947). Each of these is representative of somewhat different depositional environments which may be intergradational as the environmental conditions merge.

Pure quartz sandstone is the most widespread and representative stable shelf type. It is marked by prominent cross lamination with foreset beds as much as 10 feet thick, and cut-and-fill structure. Quartz and a small percentage of stable heavy minerals are the only constituents. These are thoroughly mixed into a homogeneous concentrate of approximately the same settling velocity. The quartz is extremely well sorted and the size of the heavy minerals compared with that of the quartz is in direct proportion to the densities of the minerals (Rubey, 1933). High sphericity and roundness commonly characterize the grains. This should not be interpreted as good evidence of the derivation of such material from pre-existing sandstones but of continual reworking of the deposits by the waves and currents prior to deposition in the final resting position. Krumbein (1940) has demonstrated that pebbles become well rounded and attain high

sphericity after short lineal transport in streams; whereas, Thiel (1940) and Alling (1944) have shown that sand grains are not rounded or shaped as rapidly and that longer transport is necessary particularly for quartz. Their data do indicate, however, that a high degree of rounding and sphericity is possible for sand which is under continued transport for even a few months.

Pitting and frosting, commonly observed in the quartz grains and in some of the heavy minerals, appear in large degree to be a solution phenomenon (etching) as shown by Lamar (1928). Inasmuch as the degree of solution is a function of the length of time the solute is in contact with the solvent, it seems probable that the longer the grain is in direct contact with sea water the greater is the etching; whereas, after burial, solution may be retarded or micro-stylolitic intergrowth may occur (Sloss and Feray, 1948).

Quartz-glauconite sands are closely related to, and are commonly intergradational or intercalcated with, sands of pure quartz type. Cross lamination is prominent but generally on a somewhat smaller scale than in the pure quartz type. Glauconite may be scattered throughout the sands but is more commonly concentrated at intervals in certain beds. The burial fauna is more varied, and, whereas the pure quartz type contains worm borings and a limited number of mollusks, the quartz-glauconite beds contain more organic remains, among which is a greater variety of benthonic forms. Deposition is apparently slower, more quiescent, and may require restricted circulation to form anaerobic environments (Hendricks and Ross, 1941). When glauconite is forming, sand deposition must effectively cease in those areas, but interspersed with quiet intervals must be periods of active mixing and redistribution of quartzose and glauconitic components.

Quartz-iron oxide sands are typical of redbeds and consist predominantly of quartz grains coated with an iron oxide film. Except for this coating they have the characteristics of the pure quartz type and many are intergradational with them. Many quartz-iron oxide sands are closely associated with evaporites, forming marginally to an intracratonic basin. From such an environment the red sands may extend landward for some distance into the realm of continental conditions. Certain ores of the Clinton type appear to belong to this group since they consist in part of nuclei of rounded and pitted quartz grains (Alling, 1947).

Quartz-muscovite type sandstones are not common, but they may occur as channel fillings, and as thin sheets of limited areal distribution. They are dominated by quartz, commonly iron oxide-stained and in subangular or angular grains. Muscovite is the second most important mineral and is concentrated along the bedding. Some of the muscovite grains are 2 to 3 millimeters in diameter and some are secondary growths. The heavy-mineral suite contains more unstable varieties, and constitutes a greater percentage of the whole mineral assemblage than in other quartzose sandstones. Certain other features, as cross lamination, quartz-pebble conglomerates, quartz enlargement, silica cement, and moderately good sorting, indicate their close relationship with pure quartz sandstones.

Shales.—Shales of the stable shelf area are characterized by features which ally them to the corresponding quartzose sandstones, and as such they represent the fine-grained equivalents. The difference, however, is not merely one of size but of mineral character. The clay-mineral fraction which is swept from the areas of sandstone accumulation is associated with finely divided quartz and other minerals with slow settling velocity. Such shales are commonly remarkably uniform over wide areas and the borders are generally transitional with the associated sand or limestone. Their color is not diagnostic but shades of grayish green and dark gray to black are common. The green color appears to be due to the presence of finely divided glauconite. Dark-colored shales are related to finely disseminated carbonaceous material. The silt fraction is characterized by the dominance of quartz and a very small fraction of feldspar. Commonly the texture is extremely fine-grained so that claystones are typical, but toward the areas of sandstone deposition the grade size increases and siltstones may appear. As the area of carbonate deposition is approached the shale becomes increasingly calcareous and a common feature is the appearance of nodules of limestone embedded in a clay matrix. The Maquoketa, Simpson, and Niobrara shale show such characteristics. Widespread dark gray to black shales may require restrictions in circulation, or other environmental factors associated with the shelf, but the organic content of stable shelf shales is low. However, fossils are abundant, represented chiefly by such benthonic forms as brachiopods, pelecypods, and crustaceans, but adventitious pelagic elements may be present.

Limestones.—Carbonate deposition occurs in those areas of the shelf receiving negligible increments of detrital matter. Such areas may be demonstrably far from shore lines and beyond the reach of land-derived débris, or the carbonate deposition may take place up to the strand line if the adjacent land is incapable of supplying significant amounts of clastics (Moore, 1929). Where shales grade seaward into carbonates the gradation is marked by an increase in the calcareous content of the shales and the appearance of carbonate nodules. These increase in size and number until the nodules become limestone beds, intercalated with shales. Finally the argillaceous matter is reduced to an impurity in limestone beds and disappears as a recognizable constituent. Under other conditions shelf sandstones grade directly into shelf limestones without an intervening shaly facies; the quartzose sands develop calcareous cement, and the cement increases and dilutes the sand content until sandy limestone and finally pure limestone appear. Lower Ordovician strata in the central states characteristically exhibit sandstone-dolomite intergradations.

The textures of stable shelf limestones are of four dominant types: normal marine, fragmental, biohermal, and foraminiferal. Each of these, though distinct, is intergradational and occurs with random distribution throughout the area of carbonate deposition. Normal marine limestones occur most commonly on the shelf. They are well bedded, with individual planes of separation spaced at intervals ranging from 2 inches to 5 feet. Normally such beds are divided into blocks

by rectangular joints with faces approaching planes. The texture is fine- to medium-crystalline and uniform. Fossil fragments do not form a conspicuous amount of the rock and much of the limestone appears to have resulted from inorganic precipitation or unrecognizable algae. Whole fossils are moderately plentiful but are ordinarily difficult to recover from the massive beds. Normal marine limestone strata are commonly separated by thin partings of gray or green-gray, fossiliferous, calcareous shale which emphasizes the well defined bedding planes. Many normal marine limestones are dolomitized and have a saccharoidal texture. Chert, recognized as secondary by the replacement of fossils, is widespread as nodules, beds, and discordant masses, commonly selecting the more susceptible beds for replacement.

Foraminiferal limestones differ from normal marine types in being composed almost entirely of organic remains with texture controlled by the dimensions of the constituent tests. Dolomitization is less common, or fewer examples have been recognized, and chert occurs in only minor amounts. Two varieties of foraminiferal limestone are recognized: coarse limestone formed of tests of benthonic orbitoids or fusulinids, and chalky limestone composed of tests of smaller planktonic forms.

Fragmental limestones, like foraminiferal types, consist mostly of organic remains but with a dominance of fragments rather than whole tests. In Paleozoic limestones, dissociated columnals and brachials of pelmatozoan echinoderms are most common, although fragments of brachiopods, bryozoans, corals, or even trilobites may make up a large proportion of the beds. Post-Paleozoic limestones of this type may be formed from fragments of echinoids, oysters, or other pelecypods, and corals. Regardless of derivation, the carbonate fragments behave dynamically like clastic particles of the shelf environment, exhibiting a high degree of sorting and, commonly, cross-bedding. In the shelf zone fragmental limestones form widespread deposits with similar character over large areas, as in the Osage series of the Mississippi Valley. Also, they are localized around the flanks of reefs, in which case the fragmental texture may grade in a short distance into another type away from the reef. Fragmental limestones may be dolomitized to form a coarsely crystalline texture in which the original character of the fragments is obscure, but dolomitization and chert are less common than in the normal marine type.

Insoluble residues from normal marine, foraminiferal, and fragmental limestones contain detrital grains with the same characteristics as the grains in shelf sands and silts, in addition to chert and silicified fossil fragments.

Biohermal limestones occur in reefs scattered over the carbonate area of the shelf. Such reefs or bioherms are commonly coral-stromatoporoid or algal in formation, but important contributions by other biologic elements may be noted. In certain depth limitations reefs may occur at random over the shelf zone as evidenced by the distribution of Niagaran reefs plotted by Cummings and Shrock (1928). Such sporadic reefs are relatively small, ranging from a few feet

to a few tens of feet in diameter, of limited vertical extent, with their upper surfaces truncated and exhibiting angular relationships with overlying non-reef strata. Two textures are associated with reef limestones: one is fragmental, as previously described, and occurs on reef-flanks where material torn from the reef by wave action comes to rest; the other is associated with the reef core and results from the accumulation of a compact mass of coral, algal, and other calcareous structures with numerous voids marking the positions of soft tissues. Ordinarily, the reef core is altered to a nearly structureless, porous, saccharhoidal dolomite in which the original organic constituents are unrecognizable (Lowenstam, 1948).

CONDITIONS ON MILDLY UNSTABLE SHELVES

The stable shelf discussed in the preceding section is conceived as a broad, gently sloping area, which is tectonically inactive, or is subject to slow sinking as a unit. On such a stable shelf small eustatic changes of sea-level result in the strand line moving considerable distances. As the shelf area becomes less stable, changes in the position of the strand line may also be caused by upwarpings or downwarpings of the shelf, and greater variety in the shifting strand line may be introduced by such local movements. On the whole, the unstable shelf appears to be more negative than the stable shelf, as shown by the greater thicknesses of sediment accumulated on it. This negativism may not be uniform, however, inasmuch as some deposits, such as coal cyclothems, limestone-shale cycles, and some evaporite cycles, suggest that the movements were oscillatory, though with a net negative increment.

With prevailing shelf instability the general conditions described under stable shelves are modified. This modification appears to be largely due to a reduction in the length of time the environmental conditions act upon the material before it is buried. This lack of continuous reworking is reflected by an increase in finer detrital constituents in the sandstones, with a consequent reduction in the degree of sorting, and the appearance of minerals of less stability in the final deposits. The less well sorted sandstones are accompanied by more silty shales than form on typical stable shelves, and the limestones respond to the changed conditions in part by developing more nodular varieties. Cyclical phenomena also increase, and in general there is a discernible difference between the lithologic associations of unstable and stable shelf conditions.

Unstable shelf associations grade imperceptibly into those of the stable shelf on the one hand, and into associations of the intracratonic basins on the other. In part the unstable shelf areas include the transitions between stable shelves and the more strongly negative basins. There is seldom an exact concordance between isopachs and lithofacies; more commonly there seems to be a facies lag, where thickening occurs over a broader belt than facies change. Hence, sharp boundaries are seldom found in gradations on either side of the unstable shelf. Nevertheless, in areas large enough to extend beyond the transition zones, the unstable shelf association shows typical characteristics.

DEPOSITS ON MILDLY UNSTABLE SHELVES

Sandstones.—Sandstones designated as the quartz-potash feldspar type are arbitrarily differentiated from the pure quartz type with which they are intergradational. If the potash feldspar exceeds 10 per cent but is less than 25 per cent of the total mineral assemblage, the rock is designated as a quartz-potash feldspar sandstone. These contain organisms of the littoral and near-shore environment and many contain the fragments of land plants. They also are more poorly sorted than the pure quartz type and the size-distribution curves are generally skewed toward the coarse sizes because of a generally small amount of intergranular material. The writers suggest that where such sands become shifted from one basin to another they more closely approach the pure quartz type in their characteristics; but, if they represent a sediment of initial deposition they more closely approach shelf (blanket) arkoses. In short, if they represent sediments of one cycle of deposition the sorting is poor, the heavy-mineral suite contains minerals unstable to weathering, and interstitial clay, silt, and mica are more abundant than in other shelf sandstones. The local areal distribution of sandstones belonging to this type suggests the limited occurrence of unstable shelf areas in a region of dominant stability.

Blanket arkoses (shelf arkoses) occur in thin sheets, locally distributed, and associated with the quartz-potash feldspar sandstone. The high (+25 per cent) content of potash feldspar suggests the presence of a granitic source for the sediments, and an early and permanent burial in negative parts of the shelf. Arkoses of this type are abnormal in the list of shelf sediments and appear only where the source area furnishes arkosic débris and is not strongly positive. Such deposits also are typical of the basal part of transgressive sands on granite terranes.

Subgraywacke[4] (quartz-muscovite) sands differ from the quartz-muscovite sands of the stable shelf in several features. Their size-distribution curves are skewed toward the finer sizes and have a greater standard deviation, many as high as $2\frac{1}{2}$ phi units. The average diameter of the grain-size distribution is smaller than that of the stable shelf equivalents, and is commonly in the fine-sand size. Appreciable quantities of clay and micaceous minerals appear in the matrix between the larger quartz and muscovite grains. The percentage of heavy minerals is larger, and amphiboles and pyroxenes form a moderately important part of the heavy-mineral suite. Feldspars are present to a moderate degree.

Subgraywacke sands are widespread over areas where much of the shelf is mildly unstable; but, in relatively smaller areas of more turbulent conditions, as along stream channels or shore lines, these sands "clean up" into the quartz-muscovite type similar to stable shelf sand. These are the shoestring or channel types of deposits associated with coal cyclothem sequences and other types of

[4] The term "subgraywacke" has been suggested by Pettijohn for sands of this description. They are not true graywackes inasmuch as rock fragments and chlorite are not an important part of the sediment. Similar sands are referred to as "low-rank graywackes" by Krynine (1948).

sheet sands, such as the Bartlesville, the Bradford, and the Pleasantview sandstones.

Shales.—Whereas the typical shale of the stable shelf is claystone, the shale of the slightly unstable shelf is siltstone. These are micaceous and feldspar is one of the common minerals in the silt fraction. The colors are not diagnostic although the typical greenish gray of the stable shelf appears to be replaced by an olive-drab or gray-drab color. Nevertheless, red, brown, or black colors occur and reflect local conditions of deposition. They are gradational with the shale of the stable shelf but such cases do not appear to be common. They are, however, closely associated with subgraywackes, and dense and nodular limestones. These associations are typical of coal cyclothems of the shelf zones in the central states.

Limestones.—Limestones of the mildly unstable shelf are dense, argillaceous, and light gray or greenish gray. They are associated or interbedded with nodular, massive strata of the same colors. The dense, argillaceous varieties have an insoluble residue high in clay and silt, of which feldspar constitutes an important part. Fracture may be conchoidal. Bedding is generally thin or flaggy, commonly with sharply defined smooth bedding planes. Fossils are not common and are particularly deficient in benthonic forms.

The nodular limestones are normally not thick, ordinarily less than 50 feet. They are massive, bedded in layers as much as 5 feet thick, but in the outcrop the upper parts are in thin-bedded units. This development is largely a phenomenon of weathering in which solution occurs along incipient bedding planes and results in the thin-bedded appearance. The nodular character yields an irregular and uneven bedding, and many nodules are imbedded in an argillaceous matrix. In nodular limestones the grain size is extremely small and much of the material must be of colloidal dimensions. Hence this type of limestone may be largely a chemical precipitate in which organisms do not act as precipitants, or it may represent flocculated colloidal suspensions winnowed out of the fragmental equivalents. In either case the water in which such fine material can settle to the bottom must be very quiet, and not representative of shelf areas where wave and current action develops fragmental limestones.

INTRACRATONIC BASIN

CONDITIONS IN INTRACRATONIC BASINS

An intracratonic basin[5] develops where a large part of the shelf undergoes negative tectonic activity which decreases from a center outward. Such a condition results in a circular or elliptical area of deposition which may sink more slowly than, as rapidly as, or at a greater rate than, sediments accumulate. In any instance, the presence of former intracratonic basins is revealed by the thick-

[5] Examples include the Michigan basin, Forest City basin, *et cetera.* These are referred to by Kay (1947) as "autogeosynclines" and "zeugogeosynclines," respectively. The writers prefer to restrict the term "geosyncline" to the extracratonic linear belts of sedimentation, and to use the term "intracratonic basin" for cratonic negative elements.

ening of a time-stratigraphic interval toward a central point, or by a corresponding facies change, or both. The basin is outlined by thinner equivalents on the shelf. Once initiated, such basins remain relatively fixed in position, although the margins may expand or contract and the locus of greatest deposition shifts about. Intracratonic basins are subject to variations in tectonism from moderate negativism to stability. During times of moderate negative tendency sediment is trapped and buried rapidly without long exposure on the depositional interface; during times of relative stability the environment of the shelf prevails. All gradations between these two extremes are to be expected. The occurrence of evaporites in intracratonic basin associations is a characteristic feature and is indicative of alternations of open-sea and restricted-sea conditions. Related to this feature is the close association of reefs with basin margins.

Intracratonic basins may be associated with source areas, ranging in tectonic activity from relatively stable to strongly epeirogenic. In special cases a combination of large-scale normal faulting, and accompanying conditions of erosion and transportation requisite to the production of arkose, results in the accumulation of a thick elongate wedge of sediment. Such wedges are recognized by abnormally high isopach values for intracratonic sedimentation. This thickening within the craton places the wedge arkose association in the category of intracratonic basin accumulation, but it is not to be confused with the more common persistent basins.

DEPOSITS OF INTRACRATONIC BASIN

Sandstones.—Sandstones of the intracratonic basin resemble those deposited on unstable shelves. Subgraywackes are dominant types, and are observed in thicker accumulations than typical shelf occurrences. The basin graywackes show less local tendency to "clean up" than do their shelf counterparts.

Shales.—The shales of intracratonic basins are like those associated with the quartz-muscovite subgraywackes of unstable shelves. They generally contain a variety of minerals in the silt fraction, with mica an important constituent. Toward areas of carbonate deposition the shales increase in calcareous content, and where they border on or interfinger into an evaporite basin they are commonly red or chocolate-brown. Many basin silty shales occur interbedded with subgraywackes in relatively thick sequences. The thickened coal cyclothems of the Illinois and other basins show silty micaceous shales interbedded with micaceous sands; the general sequence of lithologic types may be present in these thickened cycles, although certain members may show greater or less development than in the thinner cyclothems of the unstable shelf. Wanless (1947) has examples of cyclothems showing thick developments of basin shales and micaceous sands.

Non-clastics.—Non-clastic deposition in intracratonic basins may follow any of several variants, and distinctions must be drawn between basins with normal connections with the open sea, and basins in which connections with the open sea are restricted. In addition, basin margins, which are transitional between basins and shelves, present special problems and merit special treatment.

Open basins of carbonate deposition reflect all the infinite gradations from slight to extreme negative tectonism. With increasing negative tendency, fragmental and benthonic foraminiferal limestones, dependent on shallow, sun-bathed sea-floors and the long-continued influence of waves and currents, would be eliminated first. Thus greater emphasis is placed upon the contributions by planktonic organisms and inorganic precipitates, and chalky, finely crystalline, or dense limestones result. Ordinarily, these are not dolomitized, perhaps because they are rapidly buried and do not linger long near the depositional interface. Some basin limestones, such as the Bone Spring of West Texas (King, 1942), are black with organic matter, dense, and largely non-fossiliferous, suggesting deposition at depths sufficient to impede circulation and bacterial decay.

Margins of basins apparently meet the ecologic requirements for persistent reef growth more commonly than other areas of epicontinental sedimentation. Fairly continuous zones of reef limestones mark the periphery of active basins and serve as one of the more obvious means of defining the limits of such basins. The reefs, with their cores and flanks, are similar to those described on the shelf but are much larger and more definitely oriented in trends. The greater size may be attributed to a continued localization of favorable conditions at basin margins, with upward growth of the reefs keeping pace with downwarping of the basin. Thus the reefs appear to congregate in that part of the peripheral zone with an optimum negative tendency. A decreased rate of downwarping causes the reefs to move basinward toward a more strongly negative area, while faster downward movement causes shelfward expansion, resulting in the transgressive and regressive reefs noted by Link (1947). Lowenstam (1948) has described inter-reef facies in which conditions approaching those of the stable shelf prevail over small areas between dominating reefs. Occasionally the marginal lagoons peripheral to reef systems have been the sites of deposition of evaporites and evaporitic carbonates. Such back-reef facies have been described by King (1942) in the Chalk Bluff and Carlsbad formations of West Texas.

Restriction of open-sea circulation and resulting barred basins appear to be controlled either by marginal reefs or by tectonics alone. Control by reefs, as in the Devonian of Michigan, the Permian of West Texas, and other examples, is the more common and the more readily visualized. A nearly complete ring of basin-margin reefs, with access from the open sea restricted to flow over the reefs and through narrow inter-reef passes, would form a typical barred basin. Other restricted basins, such as the Mississippian of the Williston basin, exhibit no marginal reefs and confinement must be explained by sinking of the basin below the level of an emergent of nearly emergent surrounding shelf. In either case, carbonate deposition in barred basins inevitably gives way to evaporite deposition if restricted waters prevail for a sufficiently long time. Typically, shelf limestones are succeeded by open-basin limestones and these by evaporites in a sequence which may be as follows: (1) normal marine or fragmental limestone, (2) dense limestone, sometimes associated with oölitic limestone, (3) dense to saccha-

roidal dolomite, (4) gypsum or anhydrite, and (5) salt. The saccharoidal dolomites are non-fossiliferous, cross-bedded, and show evidence of accumulation as sand-sized rhombs precipitated from carbonate-saturated solutions. The sequence described may be repeated in a series of rhythmic cycles, but omission of parts of cycles and repetition of incomplete cycles are common. Explanations have been sought for occurrences of thick deposits of sulphates with little or no chlorides, and for the converse situation, but no satisfactory answer in paleogeography or physical chemistry has yet appeared.

Arkoses.—Some intracratonic basins contain wedge-shaped deposits of arkose. Many of them are of considerable thickness and local in distribution. They are distinct from the arkoses of the shelf in their cross section, thickness, and associations. Basin arkoses are designated "wedge arkoses" as distinct from the "blanket arkose" of the shelf. They are also different from other deposits of the intracratonic basin in their distribution pattern. Whereas deposits of the typical intracratonic basin have a generally circular or elliptical cross section gradually thickening toward the center of the basin, the wedge arkose has a more linear distribution pattern, terminated rather abruptly at the ends, and its wedge cross section is thickest near the source of sediment supply. Hence, the wedge arkose does not occur near the center of the basin, or uniformly distributed throughout, but is normally restricted to one side. Wedge arkoses represent a special case in intracratonic behavior. They develop adjacent to a positive area bordering the basin when the positive area is undergoing very strong uplift through normal faulting (Krynine, 1948). Continued uplift results in rapid stripping of granite areas and removal to the adjacent intracratonic basin for deposition. When such a condition develops on the positive area the intracratonic basin also changes its behavior and apparently begins to sink most rapidly in a linear zone adjacent to the orogenic positive area, in part due to the downthrown side of the fault.

The strongly negative nature of the area receiving the arkose apparently results in rapid trapping of the sediment, so that once it comes to rest there is little subsequent shifting of the material. Hence, the sorting is poor and the unaltered unstable minerals are preserved. Where the wedge arkose is transitional to shelf deposits lithologic gradation is rapid.

Figure 3 (Krumbein, 1948) illustrates the rapid change from the arkose basin (Fountain sandstone) of eastern Colorado to the widespread stable shelf east and north, as shown by the shelf limestones of Kansas and western Nebraska, and the stable-shelf Tensleep sandstone of Wyoming and Montana. The Minnelusa evaporite basin suggests mildly unstable conditions on this widespread shelf.

GEOSYNCLINE

CONDITIONS IN GEOSYNCLINES

The term "geosyncline" as applied by the writers refers to elongate or arcuate tectonically mobile belts outside the stable cratonic areas. They are orthogeosynclines as defined by Kay (1942, 1947). This usage confines the term "geosyn-

cline" to extracratonic zones and limits the application of "basin" to intracratonic negative elements. There are examples of linear mobile belts as occupied by the Little Belt-Big Snowy mountain trend of Montana which have characteristic extracratonic geosynclinal associations and structures. These are off-shoots of the orthogeosynclinal trends and invade the margins of the cratons. Kay (1947) refers to these troughs as "exogeosynclines" and classes them with "geosynclines within the cratons." The writers recognize the fact that "exogeosynclines" are commonly geographically transitional between the extracratonic belts and

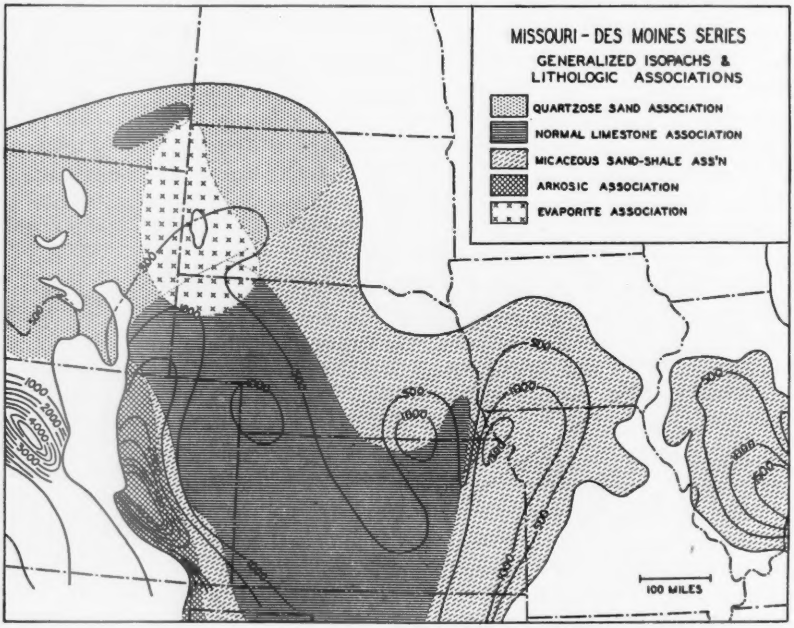

FIG. 3.—Generalized map of lithologic associations in Missouri-Des Moines series of central states and Great Plains. (After Krumbein, 1948.)

intracratonic basins. However, in lithologic associations, thickness of accumulated sediment, and orogenic history, the "exogeosynclines" are distinct from other cratonic negative elements and represent extracratonic conditions regardless of their position. Kay (1947) has pointed out the fact that orthogeosynclines are usually divisible into two parallel belts: the intensely active eugeosyncline, and the somewhat more quiescent miogeosyncline. Sediments deposited in the former carry the clearly identifiable stamp of their tectonic environment; those of the latter are less readily recognized.

The writers' concept of the geosynclinal environment is influenced by the inevitable occurrence of certain lithologic associations in stratigraphic sections which, because of position, thickness, structure, and associated igneous activity, are classed as geosynclinal. These associations indicate at least two conditions which must be satisfied by any such concept: (1) long-continued uplift in source areas to supply detritus through considerable intervals of time; (2) rapid subsidence in depositional areas to cause trapping and burial of sediments before the dynamics of the sea floor can affect them. Thus, the writers are led closer to that school of thought which pictures ancient geosynclines in terms of island arcs and tectogenes, a pattern such as that bordering the edge of the southwest Pacific (Hess, 1948). The island arcs in this concept are the actively upwarping source areas, "cannibalistically" feeding the forces of erosion, as Krynine[6] has suggested with products of earlier geosynclinal sedimentation, metamorphism, and igneous activity. The tectogenes, with their demonstrated capacity for downwarping in excess of sedimentation, are the logical depositional sites. Here should be trapped the bulk of coarse detritus eroded from emergent adjoining arcs, normally maintaining the trough in a filled or nearly filled condition, but characteristically with sufficient downwarping to accommodate the sediments without appreciable reworking. Any slackening of the strong negative tendency would bring about an excess of deposition over subsidence, requiring shifting and reworking of sediments and establishing, at least temporarily, the dynamic conditions of the shelf. When the island arcs are low or submergent coincident with continued subsidence of the tectogene troughs, detrital deposition is replaced by deposition of limestone, siliceous limestone, or chert under bathyal environmental conditions.

DEPOSITS OF GEOSYNCLINE

Sandstones.—Graywacke is the typical coarse clastic deposited in the geosynclinal trough. The characteristic green gray color is due largely to the dominance of minerals of metamorphic rocks, iron in the ferrous state, fragments of schist, slate, quartzite, and shale, and reduction in the percentage of quartz over that found in shelf or basin sandstones. Clay-size grains forming the matrix may aggregate more than 15 per cent of the total sediment, so that the larger individual fragments may be completely surrounded by the paste of clayey minerals. Pyrite both as a detrital and authigenic mineral indicates that the environment of deposition favored reducing conditions. Graded bedding, typical of graywackes, appears to develop only when the accumulating zone is well below wave base so that the material settles out of suspension and is not further disturbed before burial; hence, the large standard deviation of the grain-size distribution and the distribution curve skewed toward the fine sizes. (See Krynine, 1948, for fuller details regarding graywackes.)

There are other graywackes which have a greater proportion of quartz, which may contain glauconite and primary calcite and dolomite, and in which chert is

[6] P. D. Krynine, oral communication.

abundant. These sandstones are generally tuffaceous and are interbedded with gray, dense, siliceous sandstones containing fucoidal markings on their bedding surfaces. Graded bedding is inconspicuous, and cross-bedding may be present on a small scale. Some of the salt-and-pepper sands belong in this category. These graywackes appear to be transitional between the rapidly buried geosynclinal deposits and the more thoroughly reworked sands of the cratonic border. An example is found in the gradations of the Frontier sand from western to central Wyoming.

Shales.—Geosynclinal shales are fine-grained equivalents of the graywackes in which the percentage of fine material is increased to form a major proportion of the constituents. The resulting shale contains enough coarse débris to exhibit prominent graded bedding and a variety of minerals identical to those of the graywackes. Greenish gray and dark gray are common although other colors may locally be present. These shales are both interbedded and interfingered with the graywackes, and the occurrence of monotonous sequences of sandstone and shale of this type are common in geosynclinal sections.

Limestones.—Carbonate deposition in geosynclinal troughs occurs in two intergradational environments: the cratonic border of the geosyncline where environments transitional to the shelf prevail (miogeosyncline of Kay); and the mobile, highly orogenic belt of the geosyncline (eugeosyncline of Kay). Carbonates are common in the former, rare in the latter.

Along the cratonic border of the geosyncline, conditions of carbonate deposition closely parallel those of the open intracratonic basin. Near the ill defined edge of the adjoining shelf where negative tendency is slight, limestones such as normal marine, fragmental, and benthonic foraminiferal, may accumulate or be swept in from the shelf. Such limestones may aggregate two or three times the thickness represented by equivalents on the shelf, as is the case with the Mission Canyon and Rundle limestones (Mississippian) at the edge of the Cordilleran geosyncline. Farther away from the shelf, in a zone of greater negativism, fragmental and benthonic foraminiferal limestones dependent on shallow-water ecology and slow burial disappear and the dominant facies is the normal marine type commonly dolomitized and thick. The Knox dolomite of the Appalachian geosynclinal border is an example, and others are found in the Ordovician and Silurian dolomites of southeastern Idaho.

In the orogenic eugeosynclinal belt occurrence of limestones must represent times of marked regional subsidence sufficient to submerge the positive arcs which normally shed graywackes into the trough. Under such circumstances limestones accumulate below the depth limit for abundant benthonic forms and it is possible to have contributions by the plankton at least partly dissolved. The lithologic result is dense, organically rich, black limestone similar to types previously noted in extremely negative basin phases. Such limestones are relatively more common in geosynclines, however, and are commonly associated with chert. The chert may occur in individual beds as in the Franciscan of California or

intimately mixed with the limestone to produce a siliceous rock of almost equal and inseparable parts of silica and carbonate. The chert contains few, if any, silicified fossils although siliceous types such as radiolaria and sponge spicules are found. The chert gives the impression of primary deposition and may be related to submarine volcanism active in the eugeosynclinal belt.

SUMMARY OF LITHOLOGIC ASSOCIATIONS

Table I is an attempt to integrate the preceding discussion into a tabular summary of lithologic associations referred to their controlling tectonic frame-

TABLE 1

SUMMARY OF LITHOLOGIC ASSOCIATIONS

Observed Sedimentary Associations			*Inferred Tectonic Framework*	
Clastics		*Non-Clastics*		
Sandstones	*Shales*	*Limestones, et Cetera*	*Depositional Area*	*Source Area*
Pure quartz Quartz-glauconite Quartz-iron oxide Quartz-muscovite	Chiefly claystones; any colors; calcareous, glauconitic, carbonaceous; quartz common in silt	Normal marine Fragmental Foraminiferal Secondary chert and dolomite Random reef distribution	Stable shelf	Stable to mildly epeirogenic
Quartz-potash feldspar "Blanket" arkose Quartz-muscovite (subgraywacke)	Chiefly siltstones; any colors; micaceous; carbonaceous; feldspar may be common in silt	Nodular, with uneven bedding Dense, argillaceous	Mildly unstable shelf	
Subgraywacke	Chiefly siltstones; any colors; micaceous, calcareous, siliceous, carbonaceous; variety of minerals in silt	Thickened shelf types Evaporites (primary dolomites, sulphates, chlorides) Marginal reefs	Intracratonic basin	Stable to strongly epeirogenic
"Wedge" arkose	Red, chocolate; silty, micaceous	Nodular limestones Special evaporite sequences		Strongly positive
Graywacke	Chiefly siltstones; any colors; chloritic, siliceous, micaceous, carbonaceous, pyritic; large variety of minerals	Thick, dense, dark, siliceous	Geosyncline	Strongly orogenic

work. The first three columns, read horizontally, list the observed associations of sandstone, shale, and non-clastics. The vertical order represents an increasing degree of tectonism. The inferred tectonic framework is listed in the last two columns of the table. One column shows the inferred tectonic behavior of the

depositional area, and the other suggests a correlation between this and the tectonism of the source area.

Long-continued existence of any degree of tectonism in the depositional area develops a stratigraphic section in which the associated sandstones, shales, limestones have the characteristics shown along the corresponding horizontal row in the table. However, with changing tectonic conditions either in time or

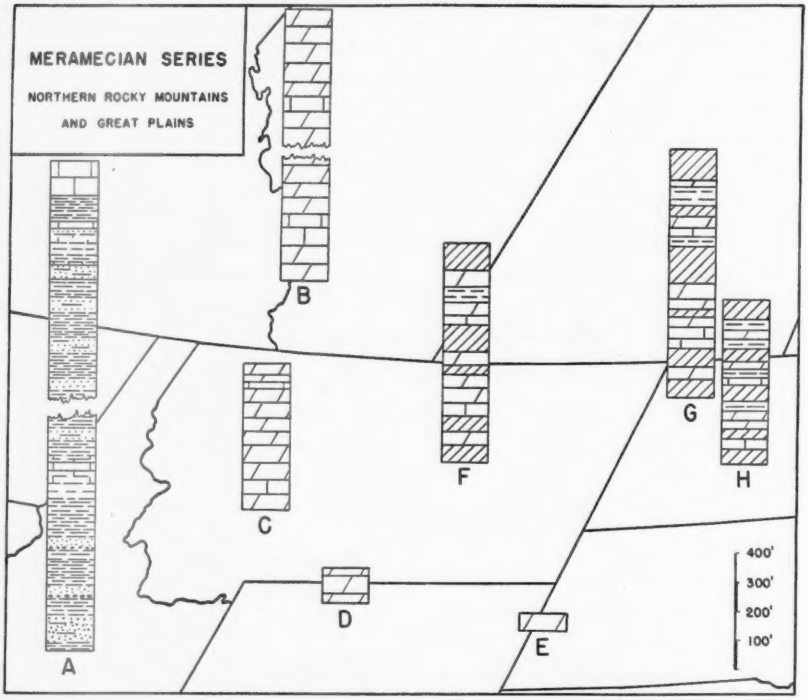

FIG. 4.—Representative sections of Middle Mississippian (Meramecian) strata in northern Rocky Mountains and Great Plains, illustrating lateral changes of time-stratigraphic unit from geosyncline to shelf to intracratonic basin. (Diagonal shading in columns F, G, and H represents anhydrite.)

space, lateral and vertical changes may be expected in the associations. Figure 4 shows lateral variations of a single time-stratigraphic unit, the Meramecian, from a geosyncline, across a shelf, and into an intracratonic basin. Column A represents the association of black shales and intercalated graywackes of the Millegan formation deposited in a strongly geosynclinal trough of the Cordilleran complex. The 100 or more feet of dolomite of the Brazer formation at the top of the time-stratigraphic unit represents a shift from geosynclinal to shelf conditions near the close of Meramecian time. Columns B and C represent Meramecian

portions of the Rundle and equivalent strata deposited in the transition zone between the miogeosynclinal phase and the adjacent shelf. Here occur dolomitized fragmental and normal marine limestones differing from the shelf equivalents chiefly in greater thickness. Columns D and E represent the thin, dolomitized, normal marine and fragmental Meramecian part of the Madison limestone of the shelf zone. Columns F, G, and H represent the Charles formation of the Williston basin, and intracratonic negative element. Periodically the area of the Williston basin was relatively stable, as indicated by extensions of shelf limestones across the area. Throughout much of Meramecian time the basin was markedly negative in tendency and at least three evaporite cycles from primary dolomite to anhydrite may be traced from well to well.

Figure 3, mentioned in connection with arkose, is a generalized map based on lithologic associations in the Missouri-Des Moines series. The map patterns are based on the dominance of certain groups of lithologic associations as listed in Table I. In addition to the wedge arkose association in eastern Colorado and the stable shelf limestone and sandstone associations of Kansas, western Nebraska, and Wyoming-Montana, the map shows unstable shelf or mild intracratonic basin associations in the Minnelusa evaporite sequence of western South Dakota. The micaceous sand and silt associations (subgraywackes) of northern Nebraska, Iowa, Missouri, Oklahoma, and Illinois represent unstable shelf associations in the thinner parts and intracratonic associations in the thicker deposits of the Forest City and Illinois basins. Coal cyclothems are typical of these subgraywacke associations with the development of thicker sand and shale members in the basin areas.

Figures 3 and 4 show the broad lateral changes in tectonic control for time-stratigraphic intervals. However, a single well may show alternations of markedly different lithologic associations. To the extent that such alternations may show lithologic characteristics referred to different vertical positions in the table, they are to be interpreted as indicating variations in the tectonic behavior of the area penetrated by the well.

CONCLUSIONS

A critical review of the preceding pages reveals certain departures from the thesis that the tectonics of the depositional area is the most important factor in controlling sedimentary facies. Wedge arkoses, for instance, are apparently associated with large-scale normal faults within the craton and it seems obvious that the petrologic character and tectonic activity of the source are the controls on the character of the resultant sediment. Thus, an intracratonic fault of insufficient magnitude to cause erosion of large volumes of granite will have little effect on arkose sedimentation; similarly, a moderately large fault in an area of relatively thick sedimentary cover will not result in arkoses until the basement is exposed, and even then the petrology of the basement rocks may not supply arkosic débris. Hence, it is possible in special cases to raise source conditions to the most important controlling factor above depositional tectonics.

Another apparent discrepancy lies in the lag of facies changes behind tectonic changes as revealed by isopachs. Shelf sands and shelf limestones thicken appreciably as they approach geosynclinal borders, the thickening continuing into the geosyncline for an appreciable distance before the tectonic influence of the geosyncline radically affects the character of sedimentation. A plausible explanation of this apparent anomaly is sought in the hypothesis that isopachs reflect the degree to which negative movements occurred. It is the writers' opinion that the most significant factor is the speed with which a sedimentary particle passes through the depositional interface and that this is a function mostly of the rate of subsidence. Thus, if sands or organic calcite fragments remain sufficiently long on the sea floor subject to the dynamic and biologic environment of the littoral or neritic zones, shelf facies will result. However, if conditions of rapid burial exist, the sediments are passed quickly through the interface and basin or geosynclinal facies are formed. It appears that the critical boundary in terms of rate of subsidence does not commonly coincide with the tectonic boundaries defined by degree of subsidence as recognized by isopachs, and the apparent overlap of facies and tectonic provinces results.

Geologists to refer to tectonic provinces such as the Michigan basin or the Cordilleran geosyncline without regard to changing tectonic conditions. Once tagged with a tectonic name the inference is that the province involved always maintains the characteristics implied. Studies of the lithologic associations clearly indicate in the case of the Michigan basin that all tectonic conditions from shelf to open basin to barred basin are represented. Therefore, it must be clear that any tectonic label is applicable only for the time over which the appropriate tectonism prevailed. The longer the duration of any tectonic state the greater is the imprint of that particular condition on the total stratigraphic column of the province, and thick units of similar facies result from continuity of tectonism. Similarly, rapidly changing tectonic conditions are reflected in great vertical variability of facies and cause difficulty in tectonic classification. Typically, shelves exhibit the greatest longevity of similar conditions, while basins give way to intermittent shelf conditions, and new basins are subsequently re-established at the old sites. Geosynclinal belts may persist throughout several eras, but their eugeosynclinal and miogeosynclinal phases shift in position with reference to one another and to the cratons. Moreover, even the highly mobile geosynclines are periodically subject to shelf conditions, as indicated by the occurrence of facies typical of the shelf.

Thus, all possible lateral and vertical intergradations of tectonic facies are to be expected and a province must be classified tectonically according to conditions prevailing in a limited time range. Further, at any time, stratigraphic equivalents may be expected to cover much of the entire spectrum of tectonic intensities.

The complex time and space relations of tectonic elements not only raise difficulties of stratigraphic analysis in their own right, but produce a host of secondary factors to confuse further the complete interpretation of rock sequences. Attention has been directed to the concept that the environment of deposition

(littoral, neritic, *et cetera*) shapes the sedimentary characteristics to a degree controlled by the length of time the environmental conditions affect the material before burial. Just as arkoses reflect conditions in which source areas rise to first importance, so apparently may stable shelf sandstones indicate conditions in which the environmental factors rise to first importance by virtue of their length of application. It is thus emphasized that although the writers have related sedimentary facies primarily to tectonic factors, it is believed, nevertheless, that the whole story must include environmental and other factors which in special circumstances may dominate the development of sedimentary lithologic associations.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32 NO. 10 (OCTOBER, 1948), PP. 1948-1979, 13 FIGS., 2 TABLES

PENNSYLVANIAN STRATIGRAPHY AND STRUCTURE, VELMA POOL, STEPHENS COUNTY, OKLAHOMA[1]

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ABSTRACT

About 4,340 feet of marine strata, the Springer, Dornick Hills, Deese, and Hoxbar formations were deposited during the Pennsylvanian. The area was then subjected to folding and thrusting. An eastern block was complexly folded, overturned, and upthrust southwestward against a similarly deformed but structurally higher autochthonous mass. Subsequent erosion of highs was followed by burial under 1,000–2,000 feet of Permian redbeds.

INTRODUCTION

The Velma pool is in the E. ½ of T. 1 S., R. 5 W., Stephens County, Oklahoma, and extends into adjoining townships at the southeast corner. On the surface a prominent northwest-southeast anticlinal ridge is formed of the red sandstone series of the Permian Wichita-Clearfork formation.[3] This formation and the underlying Pontotoc group form a mildly arched red clastic blanket which masks a body of highly disturbed rocks below. The rocks beneath the unconformity which are reached by wells consist principally of about 4,340 feet of Pennsylvanian beds though several deep wells have penetrated to the Simpson group. This paper discusses the stratigraphy and structure of the buried and disturbed Pennsylvanian section.

PREVIOUS WORK

Published information about the Velma pool is limited to comments on the Velma-Cruce surface structure and production statistics. Goodrich[4] states that

[1] Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, Faculty of Pure Science, Columbia University.
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[2] Land and Geological Department, Phillips Petroleum Company.

A pre-Virgil areal geologic map (Fig. 9), the key to the Velma structure, was constructed from well logs after the correct succession of Pennsylvanian beds was established (Fig. 3). To avoid map crowding, only wells 1,000 feet or deeper are shown in illustrations. This eliminates a large number of shallow wells producing from Permian rocks in the SE. ¼ of T. 1 S., R. 5 W., which are normally spotted on maps of the Velma pool.

Long experience in interpretive logging of well samples from southwest Oklahoma and a precise attention to detail enabled Paul L. Bartram, Ardmore district geologist for the Phillips Petroleum Company, 1938-1947, to construct and assemble over a period of years a collection of sample logs of the Velma pool which represent an invaluable body of homogeneous information. Also helpful were numerous logs by his associate, B. W. James. Data of this sort are critical to the solution of a complex, wholly subsurface problem and make possible the synthesis here presented. Certain electric logs were helpful. Valued advice and guidance were given by E. I. Thompson, W. H. Courtier, I. Curtis Hicks, and Paul L. Bartram, members of the geological department of the Phillips Petroleum Company. Professors Marshall Kay and Walter H. Bucher of Columbia University offered invaluable constructive criticism. Thanks are tendered to Mrs. Shirley Scott and Charles Cushman for assistance in typing and drafting.

[3] Frank Gouin, "Stephens County," *Oklahoma Geol. Survey Bull. 40*, Vol. 2 (1930), p. 23.

[4] H. B. Goodrich, "The Past and the Future," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 4 (July–August, 1921), p. 454.

Velma was among the first pools located on geological advice. Storm[5] notes that the Velma-Cruce anticline forms a topographic ridge with 300 feet of relief. It is the most prominent drainage divide between the Arbuckle and Wichita mountains and causes an indentation in the Duncan sandstone escarpment visible on the geological map of Oklahoma.[6] The discovery well, The Texas Company's Frensley No. 1 in Sec. 36, T. 1 S., R. 5 W., was completed on July 25, 1917. Early oil and gas production was from Permian sands ranging in depth from 400 to 900 feet.[7] Deeper drilling resulted in production from numerous Pennsylvanian sands and porous zones in the Simpson formation.[8]

REGIONAL SETTING

The Velma anticline is on the axis of a deep Pennsylvanian depositional basin, trending northwest-southeast, termed the Anadarko-Ardmore geosyncline by Paschal.[9] The easternmost surface expression of this geosyncline is in Carter County and is represented by the complex Arbuckle anticline, as defined by Dott,[10] together with the associated Ardmore basin, a deep, highly compressed synclinorium. The geosyncline can be traced still farther east in wells beneath the Cretaceous overlap, and according to van der Gracht[11] continues indefinitely under the Ouachitan allochthone. Northwest of the Arbuckle anticline-Ardmore basin area the axis of the trough extends into northeast Stephens, northeast Comanche, southeast Grady, and Caddo counties, Oklahoma. In western Caddo County the axis bends, trending almost due west, and continues nearly to the Oklahoma-Texas Panhandle line. In Carter, Stephens, Garvin, Grady, and Caddo counties a series of buried mountain structures has caused the oil and gas accumulation in the Graham, Fox, Milroy, Velma, Cruce, Robberson, Knox, Chickasha, Cement, Apache, and other fields.

The Amarillo arch, Wichita Mountains, North Duncan, Empire, Comanche, Loco, Healdton, Hewitt, and Brock oil-pool structures, together with the Criner Hills, comprise a complex anticlinal trend which forms the southern boundary of the geosyncline. Throughout its length the axis of the geosyncline is only 18–20 miles north of the Wichita-Criner Hills axis. Consequently some Pennsylvanian

[5] Willis Storm, "The Velma Oil and Gas Field, Stephens County, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 5 (September–October, 1921), p. 628.

[6] Robert H. Dott *et al.*, "Discussions at Permian Conference, Norman, Oklahoma, May 8, 1937," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 12 (December, 1937), p. 1561.

[7] Willis Storm, *op. cit.*, p. 629.

[8] Joseph L. Borden, "Developments in Oklahoma in 1941," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 6 (June, 1942), pp. 1058–72.

[9] E. A. Paschal, "Major Tectonic Provinces of Southern Oklahoma and Their Relation to Oil and Gas Fields," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 1 (January, 1941), p. 3.

[10] Robert H. Dott, "Pennsylvanian Paleogeography," *Oklahoma Geol. Survey Bull. 40-J* (1927); also *Bull. 40*, Vol. I (1928), p. 51.

[11] W. A. J. M. van Waterschoot van der Gracht, "Permo-Carboniferous Orogeny in South-Central United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 9 (September, 1931), p. 1000.

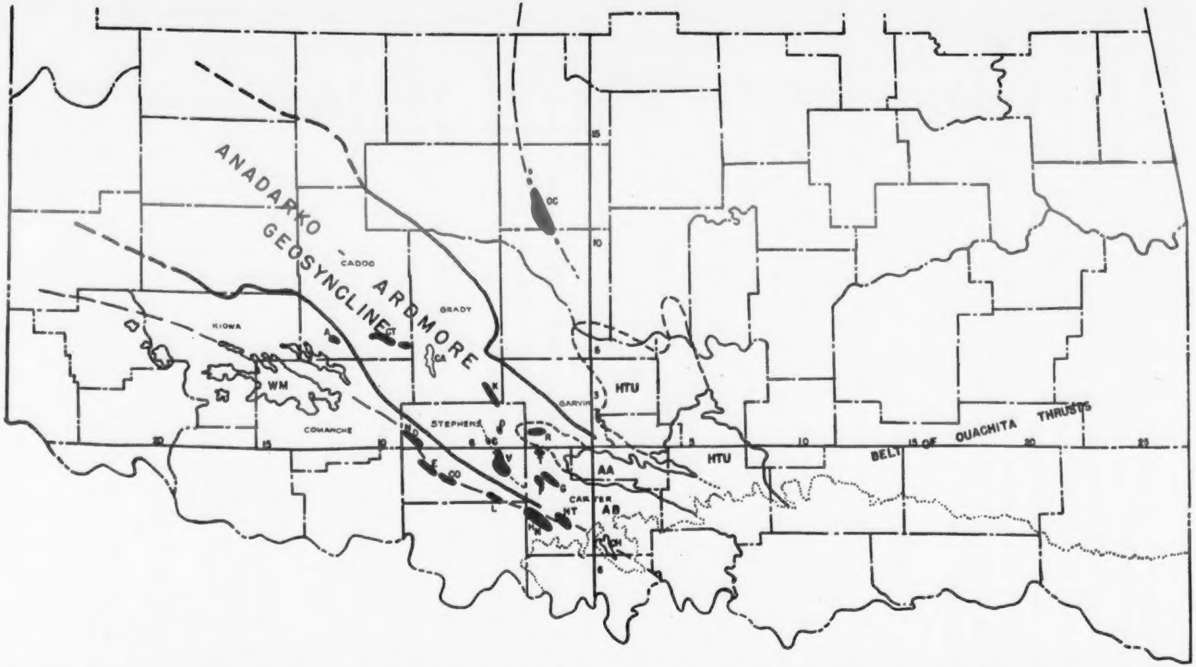


FIG. 1.—Regional index map of southern Oklahoma. County lines, Indian Meridian and Base Line with spaced townships and ranges are shown as control. Anadarko-Ardmore geosyncline is bounded by two semi-parallel, heavy northwest-southeast lines in west half of region. Solid irregular lines in south-central area indicate where early Paleozoic or pre-Cambrian rocks of Arbuckle and Wichita mountains are exposed; broken continuations indicate subsurface extension of two major components of Arbuckle Mountains, Hunton-Tishomingo uplift, and Arbuckle anticline. Wichita-Criner Hills axis is indicated by dashed line connecting Wichita Mountains, North Duncan, Empire, Comanche, Loco, Healdton, and Hewitt oil fields and Criner Hills. Isolated broken line in north-central region indicates trend of Nemaha-Oklahoma City anticline. Dotted line shows north edge of Cretaceous overlap. Solid black areas represent oil pools. Specifically named areas identified by code letters.

AA	Arbuckle anticline	CT	Cement oil pool	L	Loco oil pool
AB	Ardmore basin	D	Doyle oil pool	ND	North Duncan oil pool
HTU	Hunton-Tishomingo uplift	E	Empire oil pool	OC	Oklahoma City oil pool
CH	Criner Hills	F	Fox oil pool	R	Robberson oil pool
WM	Wichita Mountains	G	Graham oil pool	T	Tussy oil pool
A	Apache oil pool	HN	Healdton oil pool	V	Velma oil pool
C	Cruce oil pool	HT	Hewitt oil pool	CA	Chickasha gas pool
CO	Comanche oil pool	K	Carter-Knox oil pool		

formations thicken from absence to maxima in thousands of feet within this short distance. Excepting in the Arbuckle Mountains, the northern boundary, by contrast, is less sharply defined. Formations dip gently south, thin, and change facies gradually northward. Paschal[12] places the boundary at the northern limit of the Springer shale as determined from wells. In the Arbuckle Mountains the northern limit of the geosyncline is precisely defined by the line separating the Arbuckle anticline and the Hunton-Tishomingo uplift. The western boundary has not been clearly defined but it is probable that it extends across western Oklahoma into the Texas and Oklahoma panhandles and coincides with the northwestern boundary of the Bendian seas as indicated by Harlton[13] on his paleogeographic map.

PENNSYLVANIAN STRATIGRAPHIC AND STRUCTURAL HISTORY OF ANADARKO-ARDMORE GEOSYNCLINE REGION

The pre-Mississippian sediments of the Anadarko-Ardmore geosyncline are nearly 11,000 feet thick and consist principally of limestone. Cambro-Ordovician formations (the Arbuckle limestone, Simpson group, Viola limestone, and Sylvan shale) account for 9,000 feet. The Siluro-Devonian Hunton limestones, and the early Mississippian Woodford chert and Sycamore limestone make up the balance. The same formations are recognized in the northeastern half of Oklahoma where the total thickness is only 1,000–1,500 feet. The much greater thickness in the region of the Anadarko-Ardmore geosyncline shows only that this belt consistently sank more rapidly than the region on the north and east.

During Upper Mississippian and Pennsylvanian time conditions governing sedimentation differed radically from those operative in the early Paleozoic. Chesterian and lower Morrowan deposits in the Anadarko-Ardmore geosyncline are variously termed Caney shale, Mississippian-Caney, Pennsylvanian-Caney, Springer-Caney and Springer because of difficulty in determining the systemic boundary, because of post-Springer truncation, and the need for standardization of terms. The 2,500–3,500 feet of "Springer-Caney" consists of a lower shale and an upper sand sequence which is limited to the Anadarko-Ardmore geosyncline. It is described by van der Gracht as an orogenic deposit and compared with the Stanley-Jackfork sequence of the Ouachita region. Both the "Springer-Caney" and the Stanley-Jackfork sequences were derived from a common source south of the present Ouachitas since no uplifts adjacent to the Anadarko-Ardmore geosyncline were yet in existence. The presence of an orogenic deposit limited to the geosyncline is the only effect in the Anadarko-Ardmore region of the early phase of the Wichita orogeny of latest Mississippian time.[14]

[12] E. A. Paschal, *op. cit.*, p. 10.

[13] Bruce H. Harlton, "Carboniferous Stratigraphy of the Ouachitas with Special Study of the Bendian," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 8 (August, 1934), Fig. 3, p. 1026.

[14] W. A. J. M. van der Gracht, *op. cit.*, pp. 1010–12.

The late phase of the Wichita orogeny at the end of the Morrowan affected the entire Mid-Continent region. Many structures were created in Kansas and Oklahoma. Among these is the Nemaha-Oklahoma City anticline. In south-central Oklahoma the Hunton-Tishomingo uplift was formed.[15] The Wichita-Criner Hills axis experienced its principal period of folding,[16] the Anadarko-Ardmore geosyncline assumed its full proportions, and incipient structures within the geosyncline emerged and experienced local removal of the upper Springer (Springer sand) creating flank sand wedges which to-day yield oil prolifically. Flank Springer sands occur at Velma, Carter-Knox, Chitwood, Northeast Hobart, and Graham fields.

Upper Morrowan, Lampasan, Des Moinesian, and Missourian sediments of the Anadarko-Ardmore geosyncline, the Dornick Hills, Deese, and Hoxbar formations, are clastic deposits of mixed lithologic character with a total thickness of 15,000 feet near Ardmore. They have been described in the type area by Tomlinson[17] and are recognized in the subsurface part of the Anadarko-Ardmore geosyncline northwest of Ardmore, although separation of these formations in some parts of the subsurface is controversial because of lithologic similarities and absence of adequate standards. The Dornick Hills is especially difficult to identify. At Velma it consists of thin sandstones and limestones interbedded with dark gray, carbonaceous shales in the upper part which grade downward into flaky, papery, fissile shales similar to those of the Springer. The Deese formation is composed principally of shales varying in color from red to brown, gray, and green with some interbedded calcareous sands and arkosic lenses. The Deese formation rests conformably on the Dornick Hills. The Hoxbar formation consists of brown to green-gray shales at the top which grade downward into dark gray, micaceous shales interbedded with limestones and sandstones. The County Line limestone occurs near the top of the formation, and an oölitic sandy limestone occurs at the base. The Hoxbar lies conformably on the Deese excepting at the Velma, Tussy, Lone Grove, and possibly Cement and Chickasha oil fields. The oölitic sandy limestone forming the base of the Hoxbar in some places resembles the underlying Culberson zone at the top of the Deese.

The formations of this group are orogenic deposits resulting from movements ascribed to the late phase of the Wichita orogeny. Determination of the sources which provided sediment is a complex problem. Van der Gracht and Tomlinson state that both the Wichita-Criner Hills chain and a highland at the southeast, representing an early Pennsylvanian phase of the Ouachita Mountains, were co-contributors. The Bostwick conglomerate member of the Dornick Hills formation has a maximum thickness of 300 feet near the Criner Hills where cobbles as large

[15] Robert H. Dott, "Overthrusting in the Arbuckle Mountains, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 5 (May, 1934), pp. 577–582.

[16] W. A. J. M. van der Gracht, *op. cit.*, pp. 1010–12.

[17] C. W. Tomlinson, "The Pennsylvanian System in the Ardmore Basin," *Oklahoma Geol. Survey Bull. 46* (March, 1929).

as 6 inches in diameter occur. The material includes fragments of all older formations down to and including part of the Arbuckle limestone.[18] In all directions the size of the pebbles decreases, clearly indicating this area as the source. However, the bulk of the material comprising the Dornick Hills formation in the Ardmore basin seems to have been derived from Ouachita-facies rocks.[19] At Velma the occurrence of minor amounts of feldspar suggests a near-by source in the Wichita-Criner Hills chain. Studies of grain size and lithologic character of the Devil's Kitchen member of the Deese formation in the Ardmore basin indicate a southeastern source beyond the boundaries of the Wichita-Arbuckle region.[20] Presence of arkose lenses in the subsurface suggests a local source. Limestone conglomerate pebbles in the Anadarche member of the Hoxbar formation increase in size toward the Arbuckle Mountains.[21]

The Arbuckle orogeny of middle Cisco time destroyed the Anadarko-Ardmore geosyncline as a sedimentary basin. The eastern part of the Wichita-Criner Hills system was thrust still farther north, pivoting on an axis at the west end of the Amarillo Mountains, according to Dott.[22] At the same time, folding, overturning, and thrusting occurred[23] in the Anadarko-Ardmore geosyncline which created the Ardmore basin, the Arbuckle anticline and related subsurface structures at, for example, Eola, Robberson, Doyle, Cruce, and Velma.

The Virgilian series of the Ardmore basin is represented in the subsurface part of the Anadarko-Ardmore geosyncline by the Cisco formation, a sequence of fine- to medium-grained, conglomeratic, red limestone and shale. It is, in turn, a deposit resulting from the Arbuckle orogeny. Intra-geosynclinal structures were concomitantly folded, faulted, and beveled during Cisco time and the derived material deposited in surrounding synclinal troughs.

Pennsylvanian sedimentation was closed by deposition of the early Permian Pontotoc redbed blanket which spread westward over the Anadarko-Ardmore geosyncline from the newly formed Arbuckle Mountains highlands. The late phase of the Arbuckle orogeny, dated as probable early Permian by van der Gracht, was expressed in the Ouachita Mountains by overthrusting. In the Anadarko-Ardmore geosyncline normal faulting and gentle arching at this time may be related. Faults which cut the Wichita-Clearfork formation of Leonard age occur north of the Wichita Mountains,[24] and at the West Cement pool a normal fault

[18] Robert H. Dott, "Regional Stratigraphy of Mid-Continent," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 9 (September, 1941), p. 1666.

[19] C. W. Tomlinson, *op. cit.*, p. 28.

[20] C. W. Tomlinson, *op. cit.*, p. 35.

[21] *Ibid.*, p. 43.

[22] Robert H. Dott, "Overthrusting in the Arbuckle Mountains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 5 (May, 1934), p. 596.

[23] Roy P. Lehman, "Thrust Faulting in Arbuckle Mountains, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 2 (February, 1945), pp. 187–209.

[24] Hugh D. Miser, *Geologic Map of Oklahoma* (U. S. Geol. Survey, 1926).

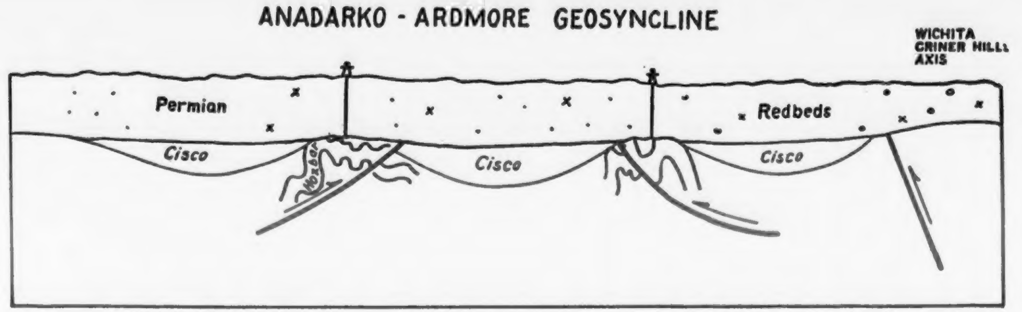


FIG. 2. (d).—Present situation. Hoxbar and all older formations were drastically deformed by folding and thrusting of Arbuckle orogeny. Directions of thrusts are diagrammatic to suggest complex of forces in geosyncline. Cisco formation was deposited in synclinal, intermontane areas. Permian redbeds then buried region. Oil was trapped in slightly arched Permian rocks and in older deformed strata below unconformity.

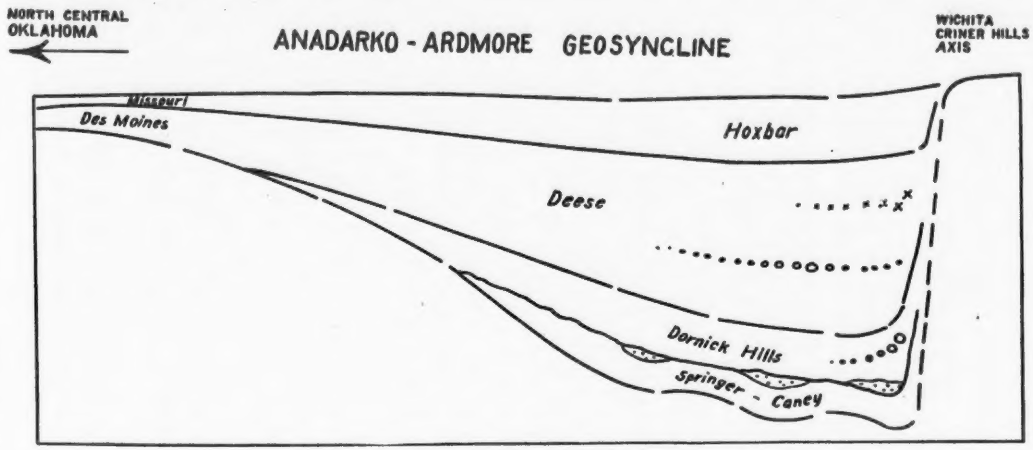


FIG. 2 (c).—Close of Hoxbar deposition. Three dominantly clastic formations, Dornick Hills, Deese, and Hoxbar, are orogenic deposits derived partly from Wichita-Criner Hills axis and partly from eastern area. (Thinning of these formations by non-deposition over growing structures within geosyncline is not shown.)

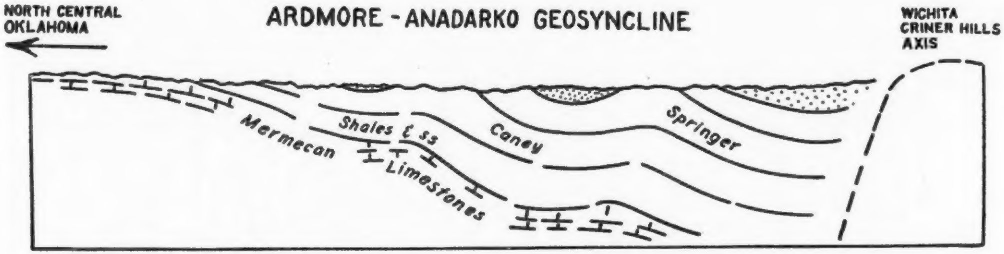


FIG. 2 (b).—Moment in post-lower Morrowan time following Wichita orogeny. Wichita-Criner Hills axis is now in existence, forming definite southern boundary for Anadarko-Ardmore geosyncline. Incipient intra-geosynclinal structures (enlarged for clarity) have been beveled. Geosyncline itself is beginning period of rapid sinking.

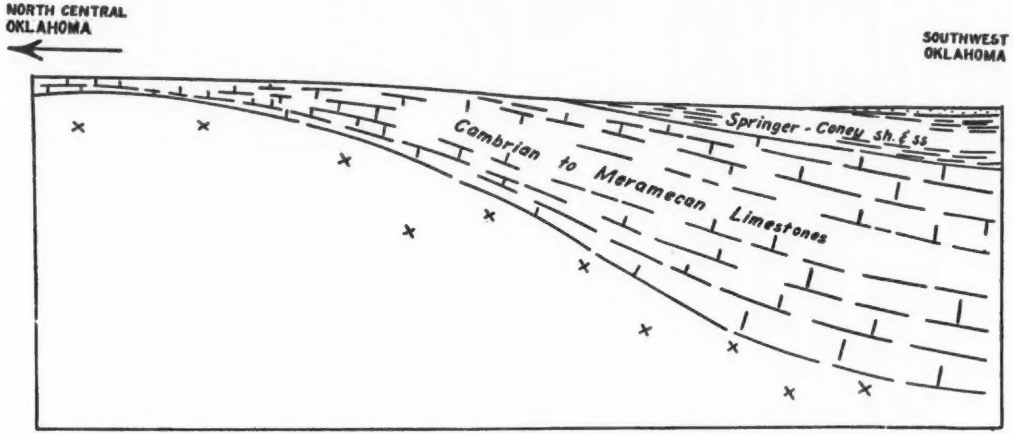


FIG. 2 (a).—Immediate post-lower Morrowan time. Cambrian to mid-Mississippian limestones are several times thicker in southwest Oklahoma than their equivalents farther north. Overlying "Springer-Caney" shales and upper sandstones form lithologic unit restricted to Anadarko-Ardmore geosyncline.

FIG. 2.—Idealized restored sections for selected moments in geologic time to illustrate significant steps in stratigraphic and structural development of Anadarko-Ardmore geosyncline. Both horizontal and vertical scales have been distorted at will to different degrees in each diagram in order to emphasize specific points.

displaces lower Pontotoc. At Velma the Permian cover (Pontotoc and Wichita-Clearfork) is gently arched.

STRATIGRAPHY OF VELMA POOL

EASTERN BLOCK

Stratigraphy in the Pennsylvanian of southern Oklahoma has provincial aspects. The widespread and almost continuous tectonic activity in the region during this period caused constantly changing environments. Hence, it is typical of these rocks that: (1) clastics predominate, (2) great thicknesses decrease to absence in short distances, and (3) facies changes are common. Although a few horizons are recognizable regionally, detailed stratigraphic description and nomenclature must be confined to local areas. Lateral lithologic variation in many places makes correlation between offset wells arduous. Nevertheless, zonal characteristics are persistent and correlation is satisfactory after a local standard has been established. Structural anomalies create correlation problems that are more apparent than real.

All strata at Velma older than Virgilian have been subjected to intense deformation and present a complex geologic pattern at the unconformity surface. An areal map of the rocks below the unconformity, a paleogeologic map, was constructed from well logs. Most of the deep wells lie east of a major thrust. For this area, therefore, a composite reference section of the 4,340 feet of Hoxbar, Deese, Dornick Hills, and Springer formations was established. The well segments from which the reference section shown in Figure 3 was compiled are listed from top to bottom as follows.

Phillips' Riviere No. 1, SE. ¼, SE. ¼, NW. ¼, Sec. 10, T. 1 S., R. 5 W., 2,112–2,389 feet
Texas' Spears No. 3, SW. ¼, NE. ¼, SE. ¼, Sec. 10, T. 1 S., R. 5 W., 2,355–2,640 feet
Skelly's Humphreys No. 1, SW. ¼, SW. ¼, SW. ¼, Sec. 13, T. 1 S., R. 5 W., 1,800–1,950 feet
Phillips' Willie No. 4, SW. ¼, NE. ¼, NE. ¼, Sec. 23, T. 1 S., R. 5 W., 1,600–2,075 feet
Turner's Riviere No. 7(3A), NE. ¼, NW. ¼, SE. ¼, Sec. 10, T. 1 S., R. 5 W., 3,340–3,598 feet
Gulf's Spears No. 5, NW. ¼, NW. ¼, SE. ¼, Sec. 14, T. 1 S., R. 5 W., 2,910–3,263 feet
Mudge's Swanson No. 15, SE. ¼, NW. ¼, NE. ¼, Sec. 23, T. 1 S., R. 5 W., 2,300–2,562 feet
Mudge's Swanson No. 14, NE. ¼, NW. ¼, NE. ¼, Sec. 23, T. 1 S., R. 5 W., 2,640–3,053 feet
Skelly's Frensley "E" No. 4, NW. ¼, NW. ¼, SW. ¼, Sec. 24, T. 1. S., R. 5 W., 2,600–3,250 feet
Skelly's Romine No. 1, SE. ¼, SE. ¼, SE. ¼, Sec. 14, T. 1 S., R. 5 W., 4,290–4,730 feet
Skelly's Doak Unit 1, No. 1, SW. ¼, NW. ¼, NW. ¼, Sec. 36, T. 1 S., R. 5 W., 1,660–2,982 feet

Many deep wells in Sec. 10, T. 1 S., R. 5 W., penetrate a nearly complete section, Turner's Riviere No. 6, SE. ¼, SW. ¼, NE. ¼, is probably the best single well in the pool to use as a standard although its apparent thicknesses are a little greater than average, the sands in the Dornick Hills are not typically developed and the larger part of the Springer sand section is lacking.

East of the thrust the Hoxbar formation is everywhere the youngest formation encountered by the drill at the unconformity excepting local patches where Hoxbar has been removed, exposing the Deese formation. The six distinctive lithologic zones recognizable in the Hoxbar permit detailed mapping of the unconformity. Thicknesses quoted in this paper are those of the reference section which represent a good approximation to a mean.

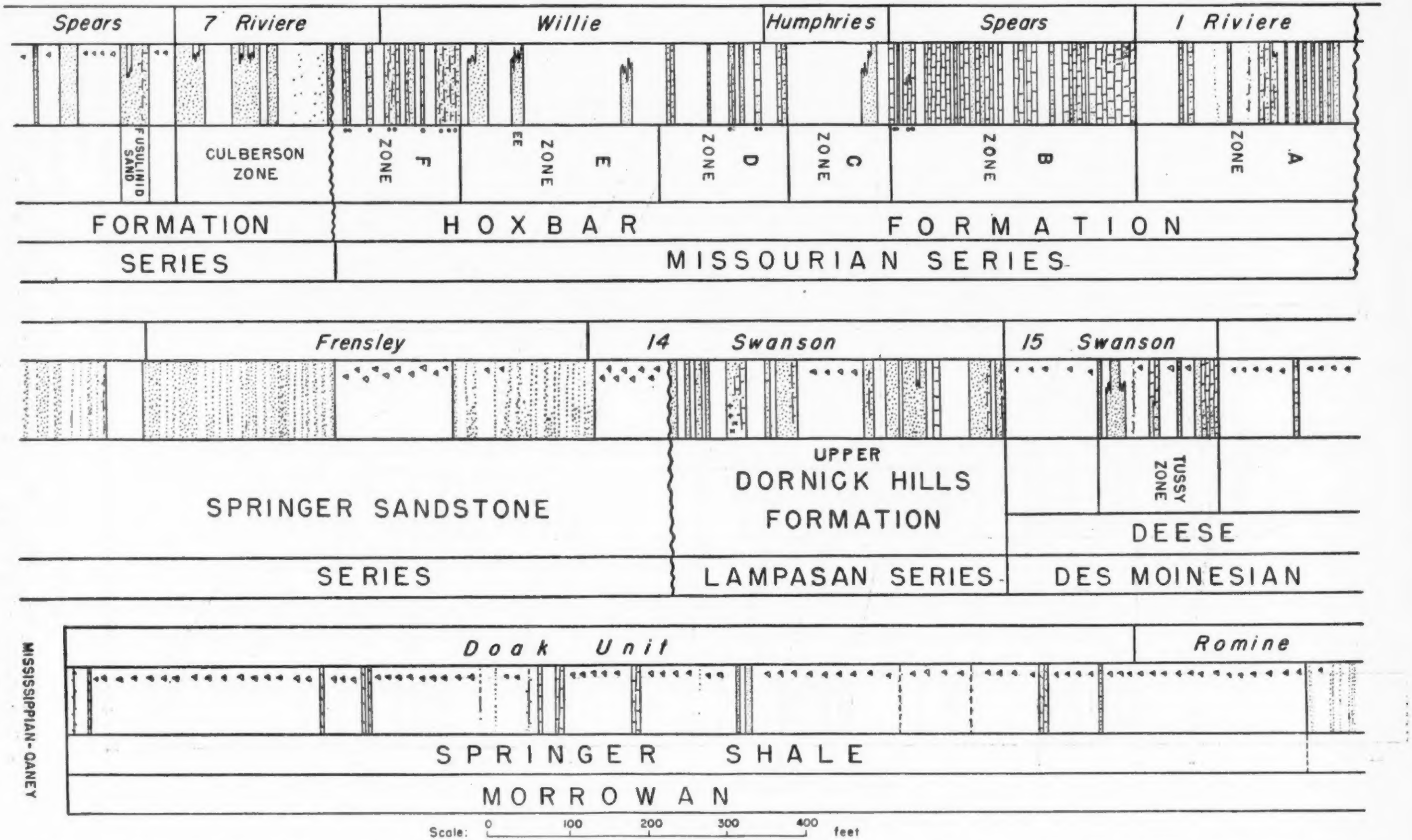


FIG. 3.—Reference section of Pennsylvanian rocks east of thrust fault, Velma pool. Names in left column refer to well from which segment is taken. Conventions used:

Limestone—bricks
Shale—blank
Sandstone—dots

Oölites—circles (beside log)
Siderite—triangles
Feldspar—X's
Chert—crosses

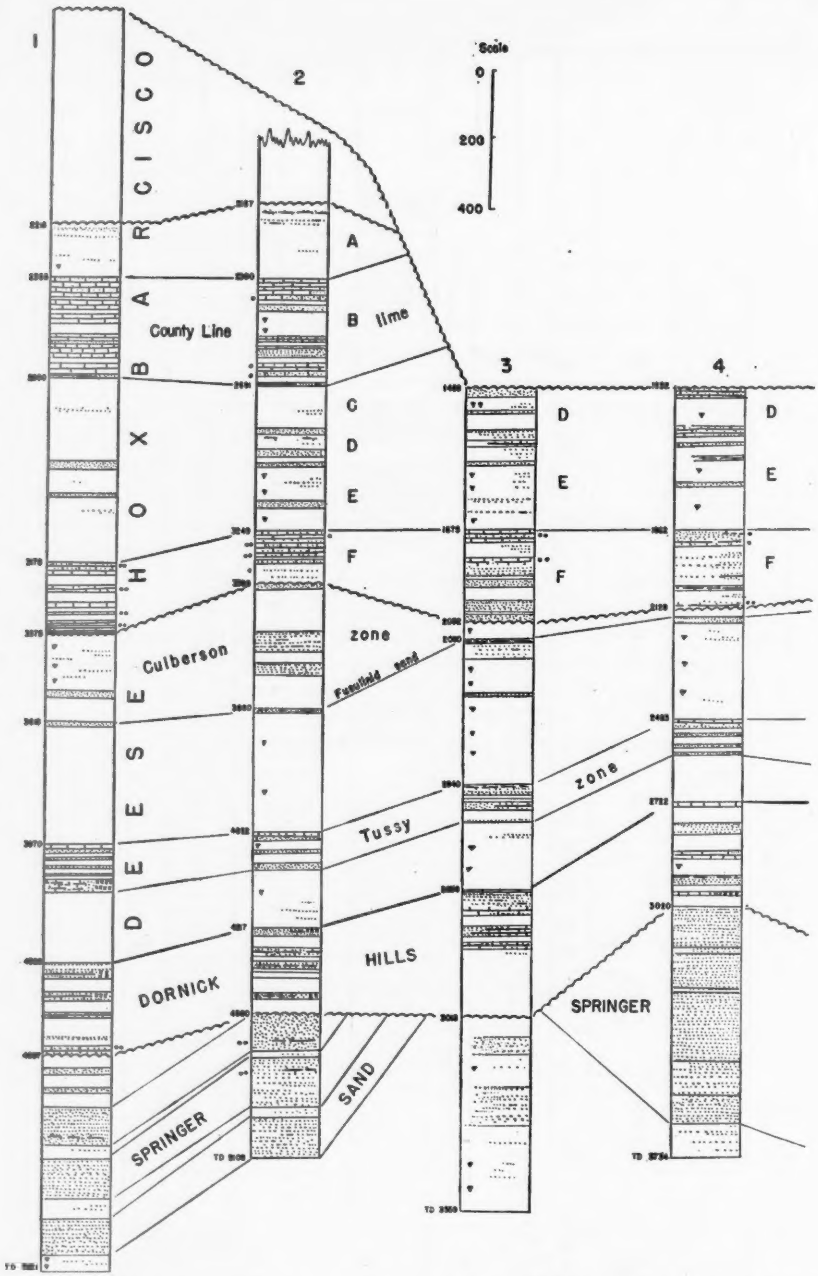
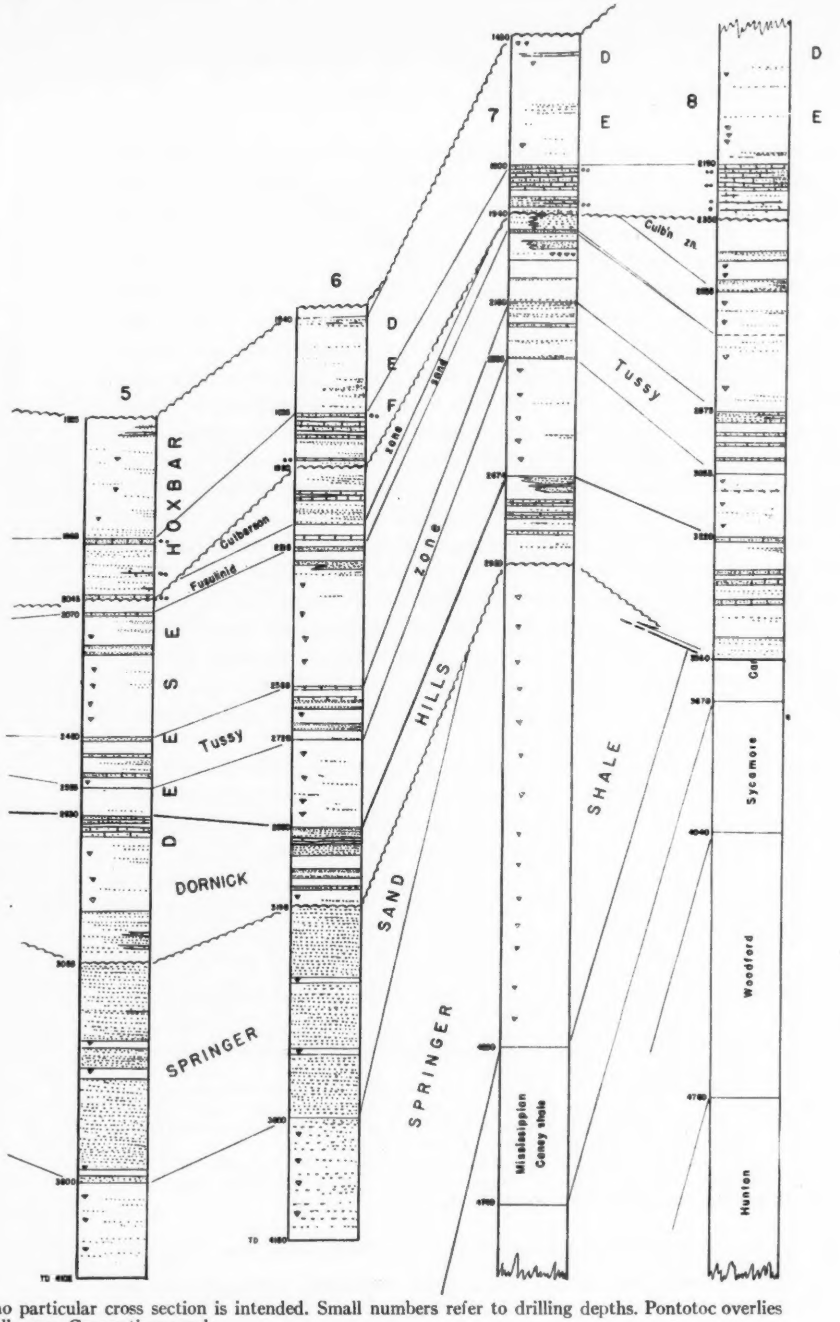


FIG. 4.—Logs of eight wells in Velma pool selected to illustrate lithologic character and correlation; highest unconformity in

Limestone—bricks Oölites—circles (beside log) Shale—blank Siderite—

1. Texas' Spears No. 3, SW. ¼, NE. ¼, SE. ¼, Sec. 10, T. 1 S., R. 5 W.
2. Turner's Riviere No. 7, NE. ¼, NW. ¼, SE. ¼, Sec. 10, T. 1 S., R. 5 W.
3. Gulf's Spears No. 4, SW. ¼, SW. ¼, SE. ¼, Sec. 14, T. 1 S., R. 5 W.
4. Phillips' Willie No. 9, NW. ¼, NE. ¼, NE. ¼, Sec. 23, T. 1 S., R. 5 W.



no particular cross section is intended. Small numbers refer to drilling depths. Pontotoc overlies all cases. Conventions used:

triangles Sandstone—dots Feldspar—X's Chert—crosses

5. Phillips' Willie No. 6, NE. ¼, NE. ¼, NE. ¼, Sec. 23, T. 1 S., R. 5 W.
6. Skelly's Frensley "J" No. 3, SW. ¼, NW. ¼, NW. ¼, Sec. 24, T. 1 S., R. 5 W.
7. Skelly's Frensley "H" No. 1, SW. ¼, NW. ¼, SE. ¼, Sec. 25, T. 1 S., R. 5 W.
8. Skelly's Kuekel No. 1, NE. ¼, SW. ¼, NE. ¼, Sec. 36, T. 1 S., R. 5 W.

Cisco formation.—Progressing downward from the surface at Velma the drill passes through the mildly arched Wichita-Clearfork formation at the surface and the underlying Pontotoc redbeds of Permian age. The next oldest rocks occur as a wedge of red shales, minor sandstones, and numerous thin clastic limestones along the eastern margin of the pool. These beds are absent west of a line striking northwest and thicken eastward at a rate of about 700 feet in ½ mile (Fig. 5). Their maximum basin thickness is probably much greater. The Cisco formation underlies the Pontotoc either conformably or with obscure disconformity and lies on older Pennsylvanian rocks with high angular unconformity. The paleotopography of the unconformity surface, as shown in Figure 6, now slopes northeast at almost 800 feet in a mile. The dating of the Cisco is based on stratigraphic position and distribution, structural relations, lithology, and analogy with other sections. The Hoxbar formation of Missourian age[25] is the youngest formation below the unconformity. The section discussed is therefore either Virgilian or lowest Permian. Rocks of similar lithologic character and stratigraphic position and with similar structural relations occur regionally as synclinal basin-fill deposits. These local basin-fills represent a waning stage of Pennsylvanian deposition. Succeeding regional burial by widespread arkosic Pontotoc clastics represents deposition of a different type and source, and may well mark the initiation of Permian sedimentation. Maximum measured thickness of the Cisco at Velma is 704 feet in Carl Carter's Jones No. 1, SW. ¼, SW. ¼, SE. ¼, Sec. 13, T. 1 S., R. 5 W., where it occurs between the depths 1,720 and 2,424 feet.

Hoxbar formation.—Missourian beds of the Ardmore basin are wholly represented by the Hoxbar formation which is 4,000 feet thick south of Ardmore.[26] At the Velma pool the Hoxbar is 1,100 feet thick and is divisible lithologically into six zones lettered from A to F. These are described as follows.

A zone.—Type from Phillips' Riviere No. 1, 2,112–2,389 feet; true thickness about 240 feet. Predominantly gray shale, intercalated with very thin (3 feet) brown, buff, and white sandstones, shaly sandstones, and arenaceous clastic limestones.

B zone.—Type from Texas' Spears No. 3, 2,355–2,640 feet; true thickness about 250 feet. Known as the County Line limestone. Predominantly gray to buff, coarsely crystalline, crinoidal limestone with thin (10 feet) sandstones and gray shales.

C zone.—Type from Skelly's Humphreys No. 1, 1,800–1,923 feet; true thickness about 110 feet. Predominantly shale with minor sandstones and sandy shales.

D zone.—Type from Skelly's Humphreys No. 1, 1,923–1,950 feet, and Phillips' Willie No. 4, 1,600–1,735 feet; true thickness about 150 feet. Predominantly gray shale, characterized by numerous thin (2–10 feet) gray to buff, sandy, crinoidal, oölitic limestones.

E zone.—Type from Phillips' Willie No. 4, 1,735–1,980 feet; true thickness about 215 feet. Predominantly gray, micaceous, sideritic shale and sandy shale with some brown sandstones. The EE sandstone subzone, a persistent horizon, is especially well developed in Mudge's Swanson No. 4, NW. ¼, SW. ¼, NE. ¼, Sec. 23, T. 1 S., R. 5 W., from 2,118 to 2,157.

F zone.—Type from Phillips' Willie No. 4, 1,980–2,075 feet and Turner's Riviere No. 7 (3A), 3,340–3,398 feet; true thickness about 135 feet. Predominantly thick (30–40 feet) buff to white, sandy, oölitic, crinoidal limestones and some micaceous gray shale.

[25] Robert H. Dott, "Regional Stratigraphy of Mid-Continent," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 9 (September, 1941).
National Research Council, Pennsylvanian Subcommittee, "Correlation of Pennsylvanian Formations of North America," *Geol. Soc. America*, Vol. 55 (June, 1944), pp. 657–706.

[26] Robert H. Dott, *op. cit.*, p. 1668. National Research Council, *op. cit.*

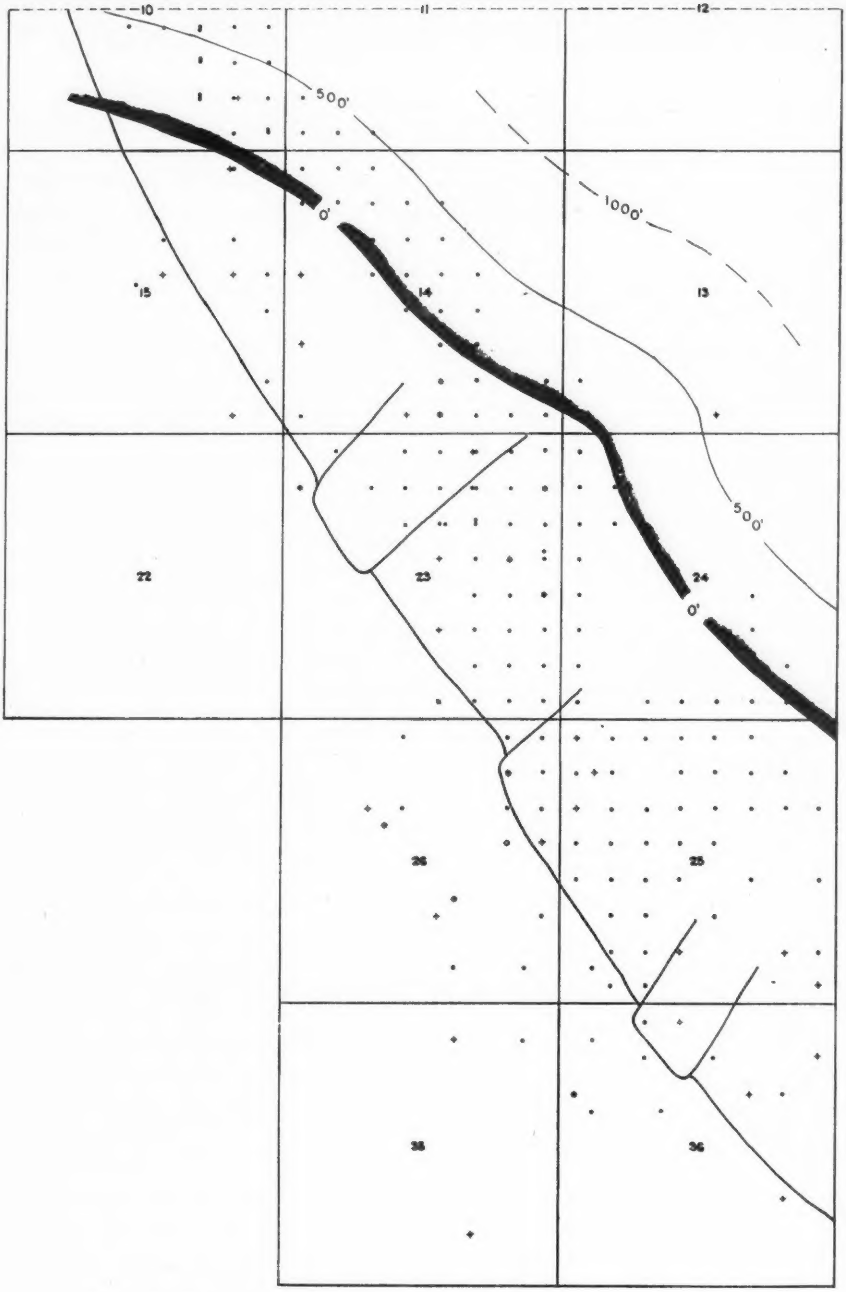


FIG. 5.—Distribution and thickness of Cisco formation. Isopach interval, 500 feet.

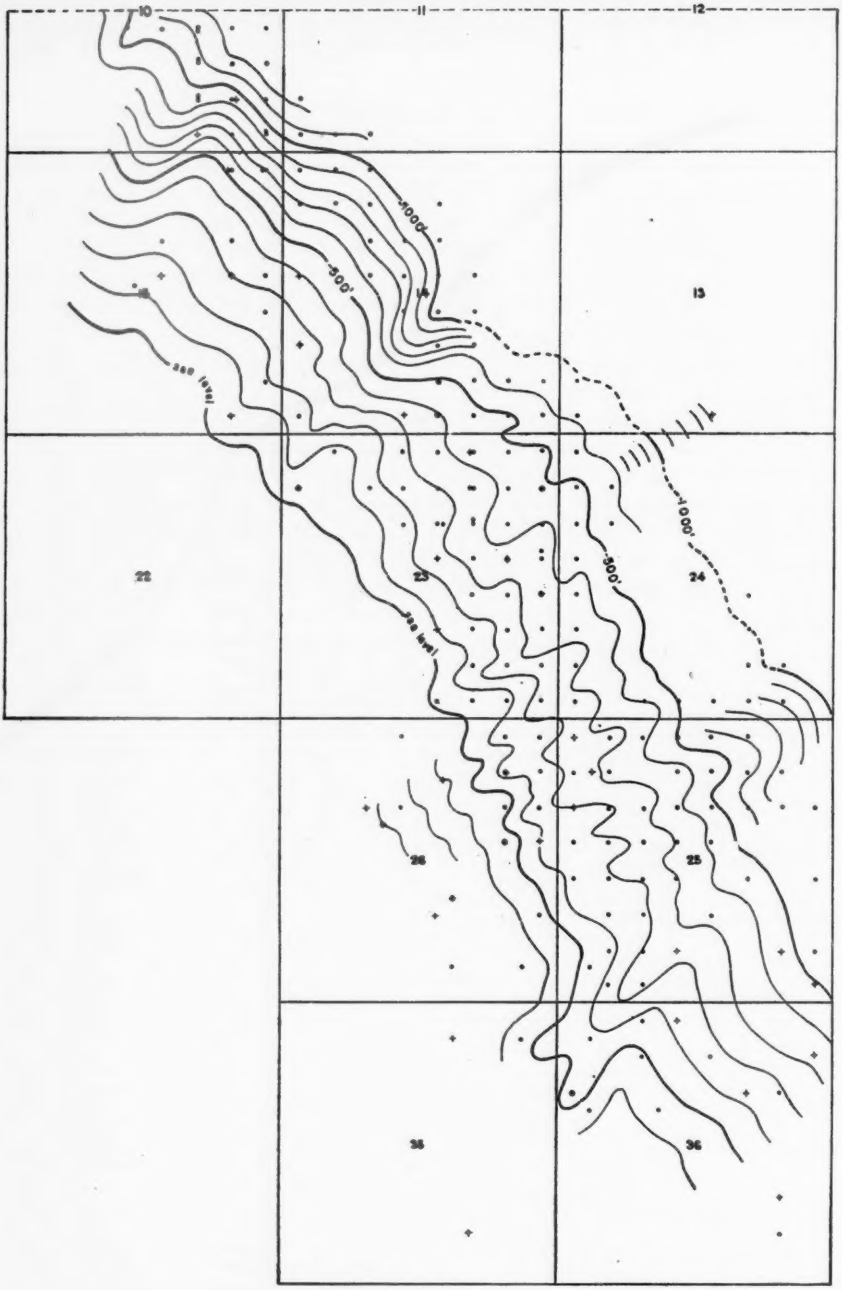


FIG. 6.—Pre-Cisco paleotopographic map. Contour interval, 100 feet. Surface is ancient, stream-dissected, northeast slope of approximately 800 feet in a mile. Erosion took place in immediate post-Hoxbar and continued on structurally high areas during Virgilian.

Deese formation.—The Deese formation is the Des Moinesian representative in the Ardmore basin where it is 8,000 feet thick.[27] At the Velma pool it is about 725 feet thick. It consists largely of dark gray shale with traces of gray-green shale although three calcareous sandy zones make up a substantial part of the formation. The standard Deese at Velma is represented by the following well segments.

Turner's Riviere No. 7 (3A), 3,398–3,598 feet
Gulf's Spears No. 5, 2,910–3,263 feet
Mudge's Swanson No. 15, 2,300–2,562 feet

The Hoxbar formation lies disconformably on the Deese at Velma. Part or all of the upper 180 feet of the Deese formation, the Culberson zone, is missing from well to well, a fact which has contributed to the controversy in determining the contact of the two formations. In all wells the F zone of oölitic sandy limestones forming the base of the Hoxbar is present, but the erratic occurrence of the upper 180 feet of the Deese is evidence for a disconformity between the two formations and the placement of beds below the F zone in the lower formation.

The Deese is not so readily divisible into units as the Hoxbar but has three recognizable zones at Velma sometimes referred to as the Culberson zone, the Fusulinid sand, and the Tussy zone.

Culberson zone.—Velma type from Turner's Riviere No. 7 (3A), 3,398–3,598 feet; true thickness about 180 feet. Predominantly fine- to medium-grained, slightly calcareous and oölitic sandstone and sandy gray shale with minor amounts of variegated shale. Named from the correlative, producing zone at Doyle pool. In places partly or totally lacking because of pre-Hoxbar removal (Fig. 7).

Fusulinid sand.—Velma type from Gulf's Spears No. 5, 2,938–2,970 feet; thickness 32 feet. Gray to buff calcareous sandstone commonly replete with fusulinids. Maynard P. White, referring to this and other sands of the same or nearly the same age in numerous wells in the Anadarko-Ardmore geosyncline, at first compared these forms with *Fusulina inconspicua* Girty, but recognized that they represent a sort of transitional type between *Fusulina* and *Triticites*. Although most geologists prefer to include this zone as part of the Deese formation, White would now prefer to erect a new genus for these forms and to consider the beds involved as transitional in age between the Missourian and Des Moinesian. No equivalent would be present in the type Missourian-Des Moinesian break.[28] Fusulinid sand lies 30 feet below Culberson zone and is widely recognized in southwest Oklahoma.

The middle part of the Deese formation contains the thickest shale sequence of the pre-Virgilian section above the Springer. The type is from the Gulf's Spears No. 5, 2,970–3,263 feet; the true thickness is about 265 feet. It is gray to dark gray and gray-green sideritic shale with a few erratic sands as much as 30 feet in thickness. This thick incompetent section may have served as a slippage zone along which opposing limbs of a drawn-out, isoclinal, recumbent fold were slid during the orogenic period following deposition of the Hoxbar (Figs. 3 and 13).

Tussy zone.—Velma type from Mudge's Swanson No. 15, 2,300–2,445 feet; true thickness about 130 feet. A zone of thin (2–20 feet) buff to brown, sandy, clastic limestones, calcareous sandstones, and sandy and sideritic shales present in varying proportions. Recognized as equivalent to producing zone in Tussy pool.

A zone of gray sideritic shale present in the Mudge's Swanson No. 15, from 2,445 to 2,562 feet, is the type for the base of the Deese formation.

[27] Robert H. Dott, *op. cit.*, p. 1666. National Research Council, *op. cit.*

[28] Maynard P. White, personal communication.

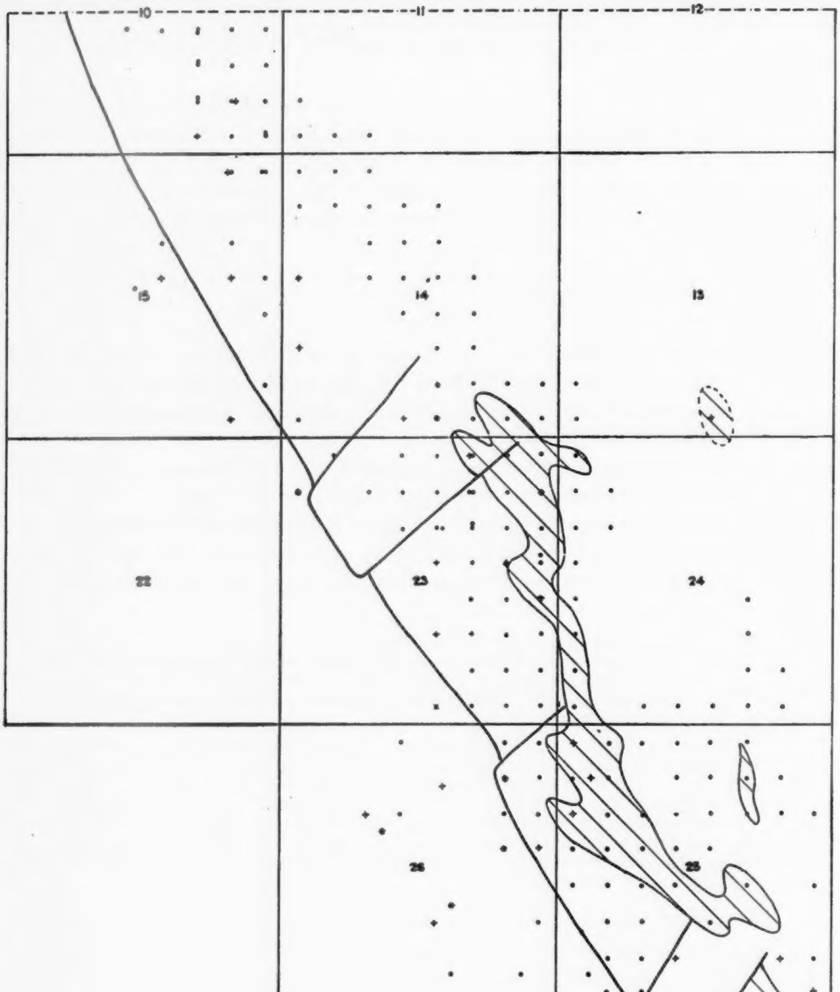


FIG. 7.—Map of Velma pool showing areas (lined) where Culberson zone is absent because of pre-Hoxbar removal.

Dornick Hills formation.—The Dornick Hills formation of the Ardmore basin, 2,800 feet thick, is upper Morrowan (Johns Valley) and Lampasan (Atokan) in age.[29] At the Velma pool it has a true thickness of about 365 feet. The standard is Mudge's Swanson No. 14, 2,650–3,053 feet. The shale section forming the base of the Deese conformably overlies the Dornick Hills formation which consists of a sequence of buff, chalky to clastic limestones, and brown very fine-grained, shaly sandstones, commonly cherty and arkosic. These are interbedded with gray, fine-textured shales similar to those of the Springer formation. No division into regularly recognizable zones is possible. The small thickness of this formation and the presence of an unconformity at its base suggest that the lower Dornick Hills (Morrowan) of the Ardmore basin may be absent at Velma.

Springer formation.—The Springer formation in the Ardmore basin is lower Morrowan (Stanley-Jackfork) in age. It consists of about 3,000 feet of dark, gray, bituminous shales containing four conspicuous sandstone members. A lower shale section called Caney and referred to the Missisippian may be Pennsylvanian.[30] At Velma the Springer formation is 2,150 feet thick and consists of an upper sandy sequence and a lower shale section. Determination of the top of the Springer formation in the subsurface is a controversial subject. A problem exists because (1) the lithologic characteristics of the gray, flaky, papery shales of the lower Dornick Hills and upper Springer formations are similar, (2) the unconformity separating these formations creates confusion, and (3) different geologists find different criteria convenient for separating one from the other. Although the Springer formation warrants special attention because of its production records, it is not within the scope of this paper to essay a solution. The reference section for the Velma pool has been compiled as follows.

Skelly's Frensley "E" No. 4, 2,600–3,250 feet
Skelly's Romine No. 1, 4,290–4,730 feet
Skelly's Doak Unit 1, No. 1, 1,660–2,982 feet

The type Velma Springer sandstone is Skelly's Frensley "E" No. 4, 2,600–3,250 feet, and Skelly's Romine No. 1, 4,290–4,512 feet; true thickness about 775 feet. Type Velma Springer shale is Skelly's Romine No. 1, 4,512–4,730 feet, and Skelly's Doak Unit 1, No. 1, 1,660–2,982 feet; true thickness about 1,375 feet. The name "Pennsylvanian-Caney" is sometimes applied to the Springer shale section.

The Springer sandstone consists of a sequence of numerous thin to medium thick (2–30 feet) brown, fine-grained, somewhat cross-laminated sandstones closely interbedded with gray, flaky, papery, sideritic shale. Little to no limestone is present. The Springer shale is gray, flaky, sideritic, and in places slightly sandy shale with some thin (2–10 feet) sandy limestones. In the approximate lower half

[29] National Research Council, *op. cit.*

[30] Robert H. Dott, *op. cit.*, p. 1665.
C. W. Tomlinson, *op. cit.*, p. 14.

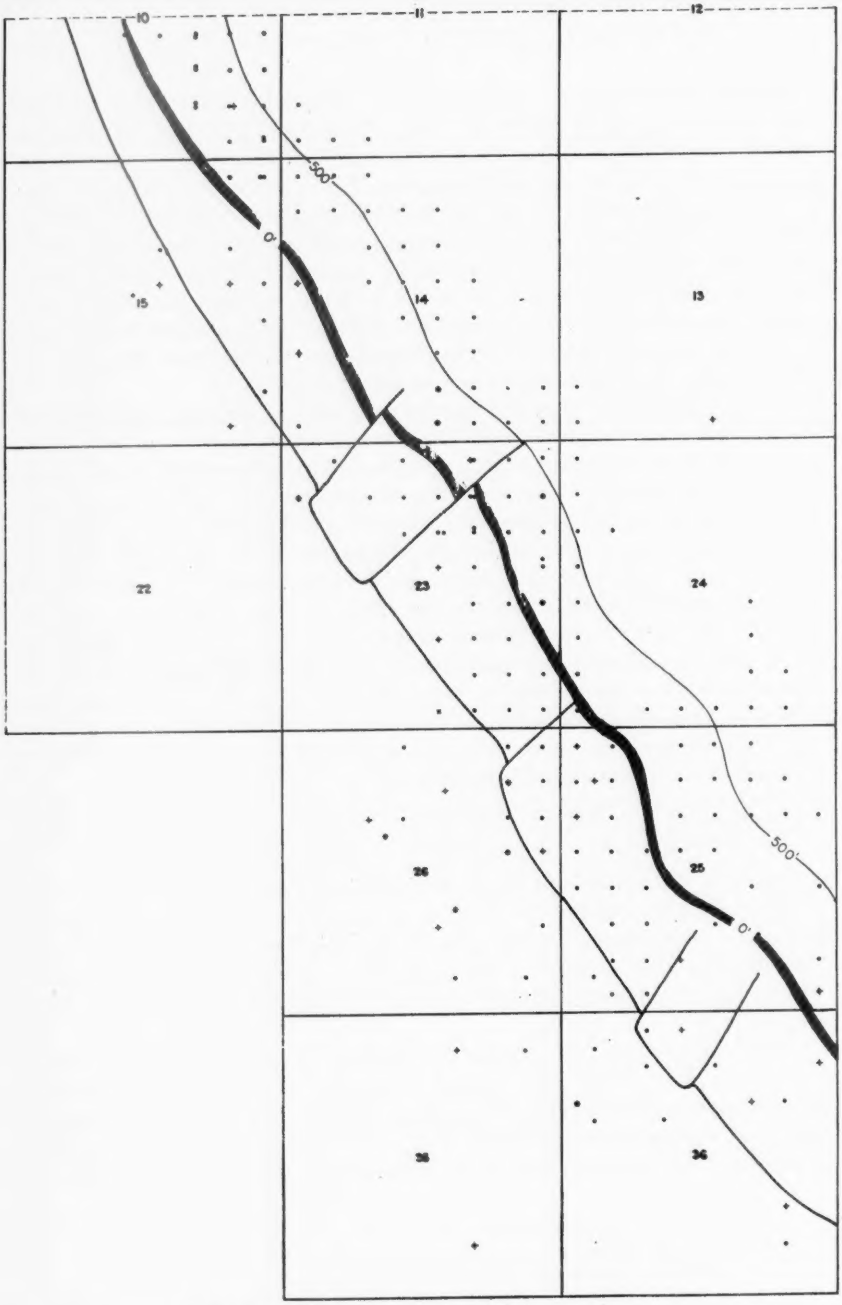


FIG. 8.—Thickness and distribution of Springer sandstone.

some gray-green shale is present and thin limestones and dolomites are more numerous. The Springer shale or "Pennsylvanian-Caney" normally lies with apparent conformity on the "Mississippian-Caney" shale.

The Springer formation of that area at Velma east of the major fault has undergone removal of the upper sandstone section from a structurally high belt. The Springer sandstone is therefore found as a northwest-southeast striking wedge thickening downdip, eastward, at about 500 feet in $\frac{1}{4}$ mile (Figs. 8 and 10). In other words, this zone was so sharply beveled in post-Springer time (late Wichita orogeny) that it thins from maximum thickness to absence in less than $\frac{1}{2}$ mile. The promising production from this flank Springer sandstone in Velma and other pools warrants precise study.

Table I lists the vertical penetration thicknesses and estimated true thicknesses of the pre-Cisco Pennsylvanian formations, unit by unit, as measured on the reference stratigraphic section (Fig. 3).

TABLE I

	Vertical Penetration Thickness (Feet)		*Estimated True Thickness (Feet)*	
A	277		240	
B	285		250	
C	123		110	
D	162		150	
E	245		215	
F	153		135	
Hoxbar total		1,245		1,100
Culberson zone	200		180	
Shaly middle Deese	293		265	
Tussy zone	145		130	
Unnamed zones (total)	177		150	
Deese total		815		725
Dornick Hills		403		365
Springer sandstone	872		775	
Springer shale	1,540		1,375	
Springer total		2,412		2,150
Velma total		4,875		4,340

WESTERN BLOCK

The foregoing discussion concerned the area east of the major fault. West of the fault deep wells are few and scattered; lithologic character is similar to that of the reference section. Four wells, all in Section 26, encounter Deese at the unconformity. (1). The Magnolia's London No. 1, NW. $\frac{1}{4}$, SE. $\frac{1}{4}$, NE. $\frac{1}{4}$, passes from Pontotoc to shaly middle Deese at a depth of 1,108 feet and is in the upper part of the Tussy zone at total depth, 1,400 feet. (2). Samples from the Magnolia's

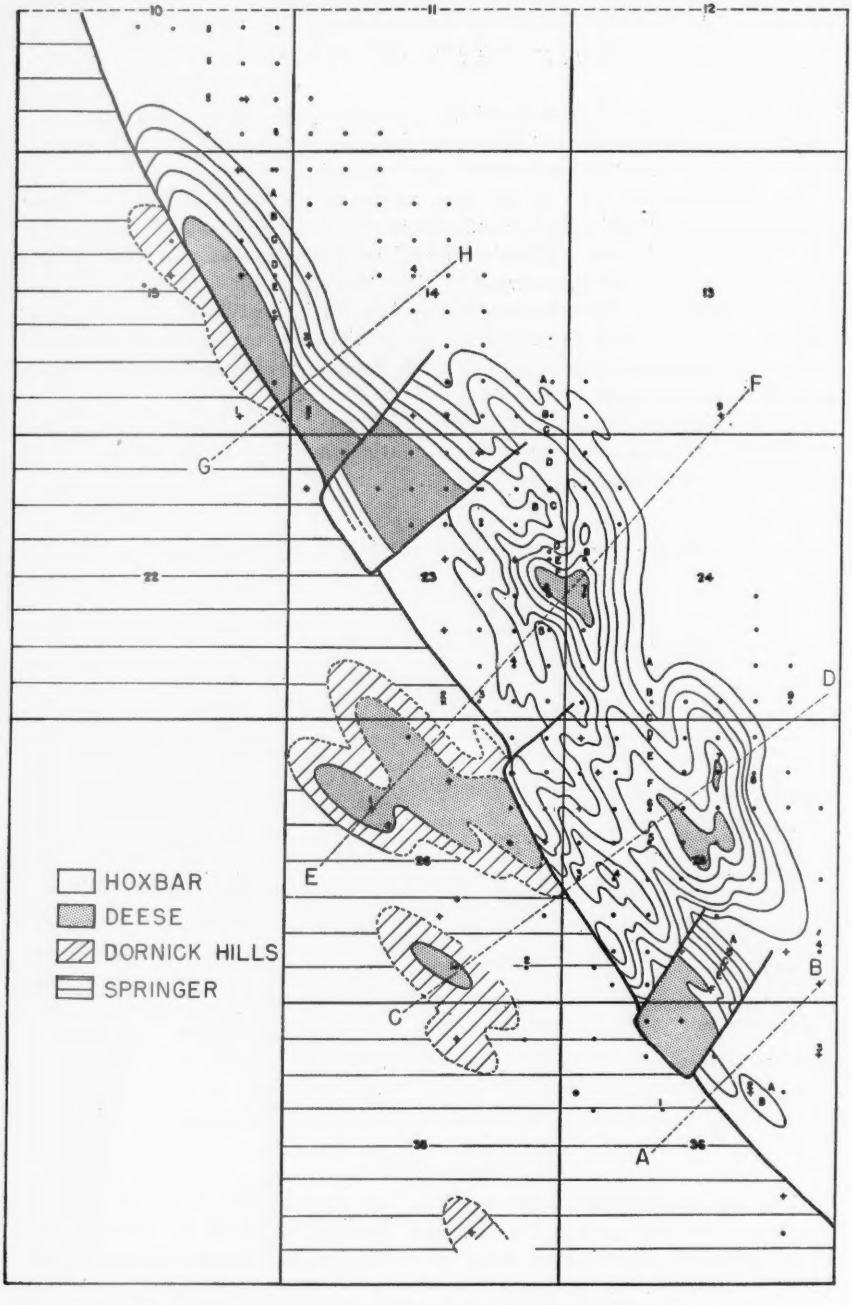


FIG. 9.—Pre-Cisco areal geologic map of Velma pool. Permian and Cisco redbeds unconformably overlie mapped formations. Hoxbar zones designated by letter.

Frensley No. 4, SW. $\frac{1}{4}$, SE. $\frac{1}{4}$, NE. $\frac{1}{4}$, start at 1,320 feet just above the Tussy zone. Dornick Hills is encountered at 1,630 feet. (3). Pontotoc lies on shaly middle Deese in Mudge's Woods No. 49, NW. $\frac{1}{4}$, SE. $\frac{1}{4}$, NW. $\frac{1}{4}$ (well No. 1 in cross section EF, Fig. 12) in which the Tussy zone, the Dornick Hills, and the Springer formations are at 1,272, 1,578, and 1,927 feet, respectively. (4). In Skelly's Selby No. 1-D, SW. $\frac{1}{4}$, SE. $\frac{1}{4}$ (well No. 1 in cross section CD, Fig. 11), low Tussy zone sandstones occur at the unconformity at a depth of 990 feet. The well passes through Dornick Hills and Springer to the total depth in the pre-Pennsylvanian.

Four wells encounter Dornick Hills at the unconformity. (1). In the Gulf's Hallmark No. 1, SW. $\frac{1}{4}$, SW. $\frac{1}{4}$, NE. $\frac{1}{4}$, Sec. 15, T. 1 S., R. 5 W., Pontotoc lies on Pennsylvanian at a depth of 1,267 feet and reaches total depth at 1,443 feet. Bartram sees similarities between this section and the Dornick Hills of the Ardmore basin. (2). Mudge's Woods No. 48, NE. $\frac{1}{4}$, SE. $\frac{1}{4}$, NW. $\frac{1}{4}$, Sec. 26, T. 1 S., R. 5 W., has a complete Dornick Hills section from 1,087 to 1,470 feet where it rests on Springer sandstones. (3) and (4). Skelly's Franklin No. 31, NE. $\frac{1}{4}$, SW. $\frac{1}{4}$, SE. $\frac{1}{4}$, Sec. 35, T. 1 S., R. 5 W., and Skelly's Robberson No. 5, NW. $\frac{1}{4}$, NE. $\frac{1}{4}$, Sec. 35, T. 1 S., R. 5 W., both pass from Pontotoc into a Dornick Hills section at depths of 1,107 and 1,188 feet, respectively, which is dissimilar to that of other wells in the pool. It is predominantly buff to white, chalky limestone with interbedded gray, calcareous shale and minor amounts of sandy limestone.

In all other deep wells within a mile wide belt west of the fault, wells pass directly from Pontotoc into Springer sandstones and shale at comparatively shallow depths.

STRUCTURE OF VELMA POOL

The main structural feature causing accumulation of oil in the Velma pool is a complex anticline trending northwest-southeast which occupies nearly all of T. 1 S., R. 5 W. (Fig. 9). The highest part of the structure occurs in Sections 22, 26, 27, and 35. It is here that oil was produced, in the early development of the pool, from shallow Permian sands. Deeper drilling on the east side of the surface high revealed accumulation in disturbed Pennsylvanian and older rocks which occur as a band extending south-southeast from Section 10 to Section 36. It is principally these flank wells, producing from Pennsylvanian and older rocks, that provide information about sub-unconformity structure. Production from rocks of similar age in the West Velma pool in the west part of T. 1 S., R. 5 W., suggest that the main Velma-West Velma anticline possesses a rough symmetry in which the west flank may mirror the structure of the east flank. A study of the pre-Permian structure of West Velma pool (west flank) would complement the following discussion of Velma pool (center and east flank).

The pre-Permian rocks in the central part of the main Velma-West Velma anticline are known from a few deep holes in Sections 4, 5, 16, 22, 26, 35, and 36. They consist principally of closely folded Springer and Dornick Hills at the unconformity. Infolded remnants of Deese are preserved along synclinal axes in Section 26.

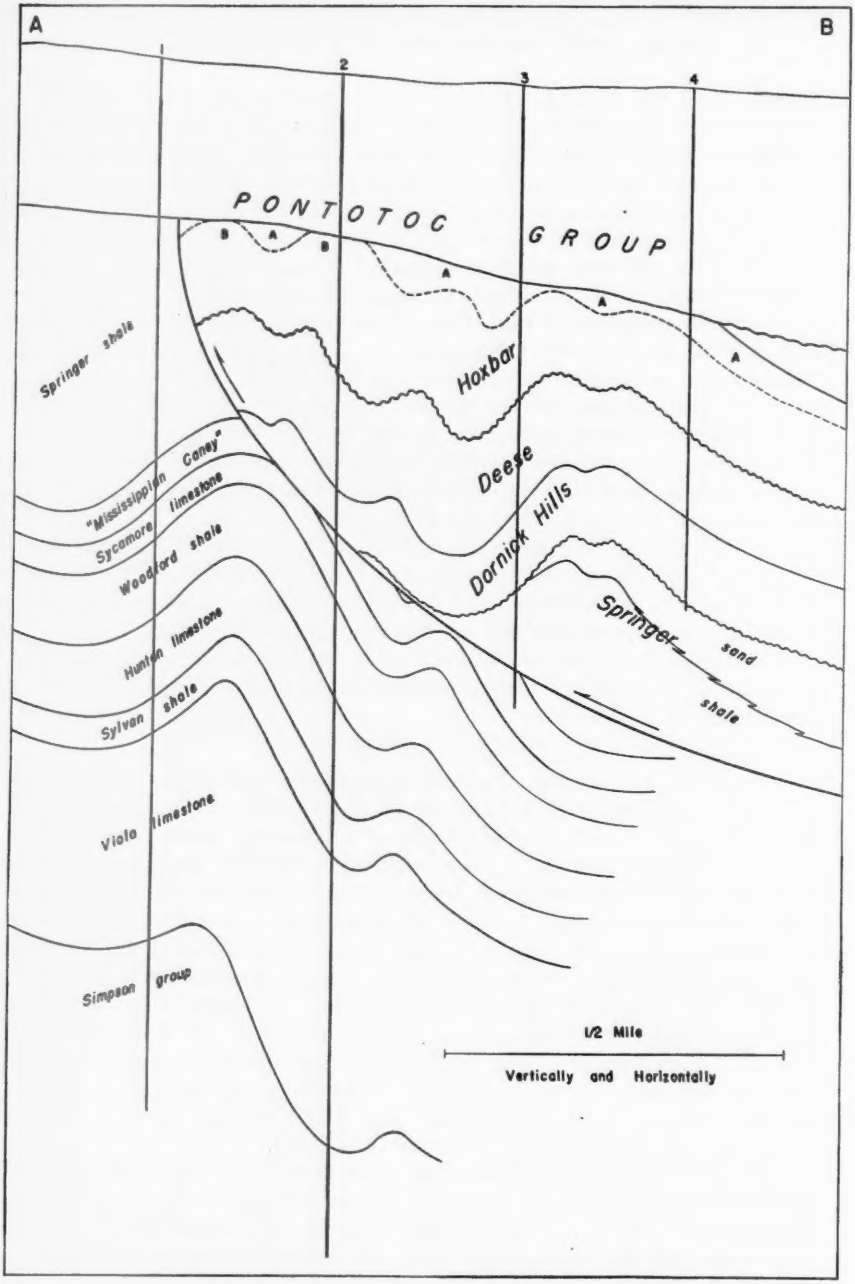


FIG. 10.—Northeast-southwest cross section *AB* (see Fig. 9). 1. Skelly's Martin No. 1-D, C., SE. ¼, NW. ¼, Sec. 36, T. 1 S., R. 5 W. 2. Skelly's Kuekel No. 1, NE. ¼, SW. ¼, NE. ¼, Sec. 36, T. 1 S., R. 5 W. 3. Skelly's Kuekel No. 2, SE. ¼, NE. ¼, NE. ¼, Sec. 36, T. 1 S., R. 5 W. 4. Champlin's Pearson No. 1, NE. ¼, SE. ¼, SE. ¼, Sec. 25, T. 1 S., R. 5 W.

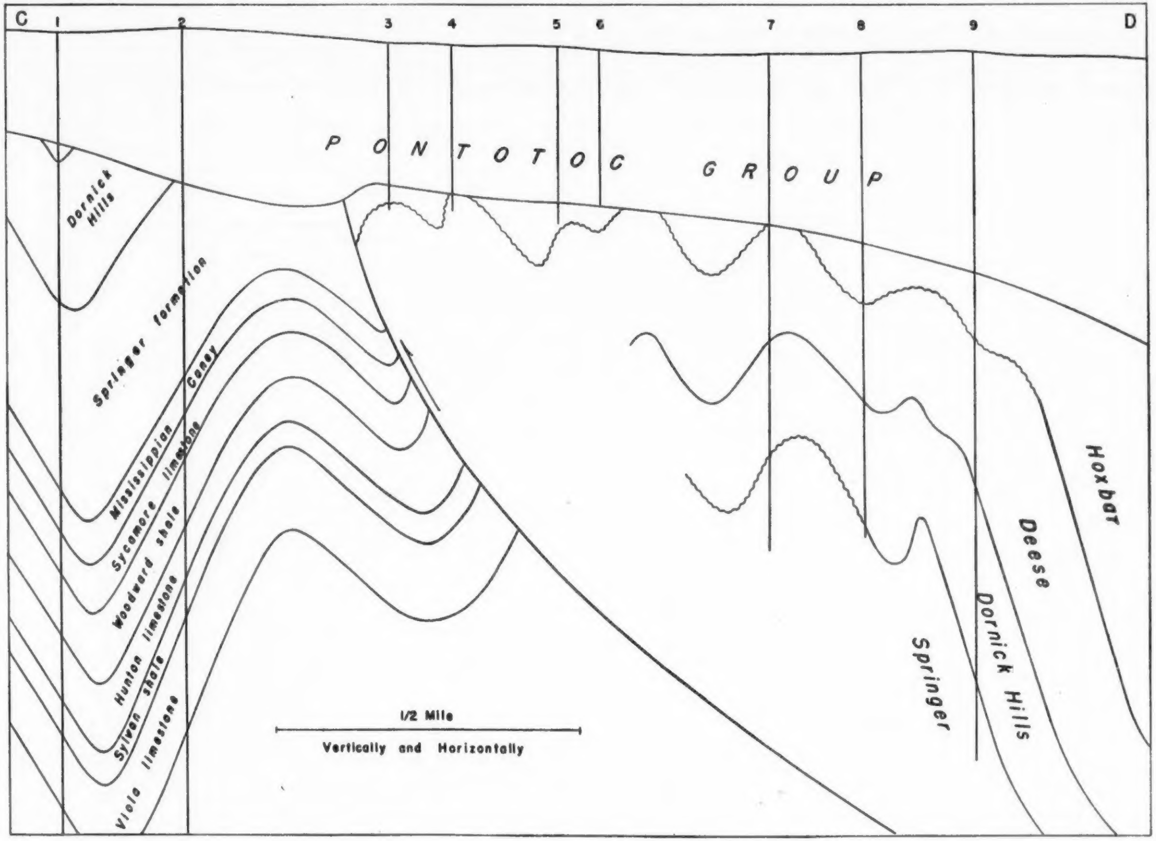


FIG. 11.—Northeast-southwest cross section *CD* (see Fig. 9). 1. Skelly's Selby No. 1-D, C., SW. ¼, SE. ¼, Sec. 26, T. 1 S., R. 5 W. 2. Skelly's Selby No. 2-D, C., SE. ¼, SE. ¼, Sec. 26, T. 1 S., R. 5 W. 3. Skelly's Winans No. 4, NW. ¼, NW. ¼, SW. ¼, Sec. 25, T. 1 S., R. 5 W. 4. Skelly's Winans Unit No. 1, NE. ¼, NW. ¼, SW. ¼, Sec. 25, T. 1 S., R. 5 W. 5. Skelly's Dickerson Unit No. 1, SW. ¼, SE. ¼, NW. ¼, Sec. 25, T. 1 S., R. 5 W. 6. Skelly's Dickerson Unit No. 2, NW. ¼, SE. ¼, NW. ¼, Sec. 25, T. 1 S., R. 5 W. 7. Skelly's Frensley No. 2, C, SW. ¼, NW. ¼, NE. ¼, Sec. 25, T. 1 S., R. 5 W. 8. Skelly's Baker No. 1, SE. ¼, NW. ¼, NE. ¼, Sec. 25, T. 1 S., R. 5 W. 9. Skelly's Baker No. 2, SW. ¼, SE. ¼, SE. ¼, Sec. 24, T. 1 S., R. 5 W.

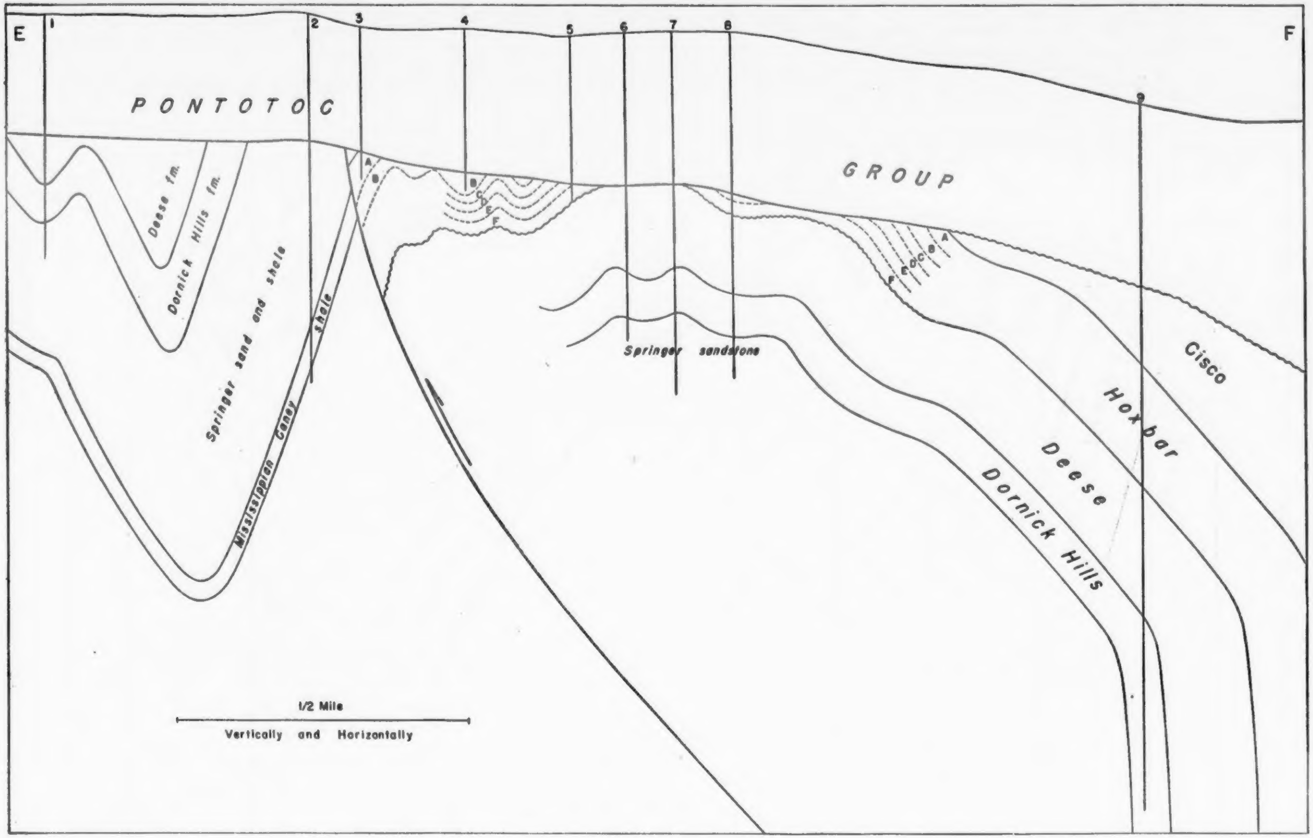


FIG. 12.—Northeast-southwest cross section *EF* (see Fig. 9). 1. Mudge's Woods No. 49, NW. ¼, SE. ¼, NW. ¼, Sec. 26, T. 1 S., R. 5 W. 2. Phillips' Quinn No. 14, SW. ¼, SW. ¼, SE. ¼, Sec. 23, T. 1 S., R. 5 W. 3. Phillips' Quinn No. 2, SE. ¼, SW. ¼, SE. ¼, Sec. 23, T. 1 S., R. 5 W. 4. Phillips' Quinn No. 6, NW. ¼, SE. ¼, SE. ¼, Sec. 23, T. 1 S., R. 5 W. 5. Phillips' Quinn No. 9, SE. ¼, NE. ¼, SE. ¼, Sec. 23, T. 1 S., R. 5 W. 6. Phillips' Quinn No. 10, NE. ¼, NE. ¼, SE. ¼ Sec. 23, T. 1 S., R. 5 W. 7. Skelly's Frensley "E," No. 4, NW. ¼, NW. ¼, SW. ¼, Sec. 24, T. 1 S., R. 5 W. 8. Skelly's Frensley "J," No. 1, SW. ¼, SW. ¼, NW. ¼, Sec. 24, T. 1 S., R. 5 W. 9. Carl Carter's Jones No. 1, SW. ¼, SW. ¼, SE. ¼, Sec. 13, T. 1 S., R. 5 W.

A northwest-southeast-trending thrust sharply divides the central part, referred to as the western block, from the east flank, or east block. The inclination of the fault is steep at the unconformity but decreases with depth, especially at the south end. The east block consists of an overturned complex anticline com-

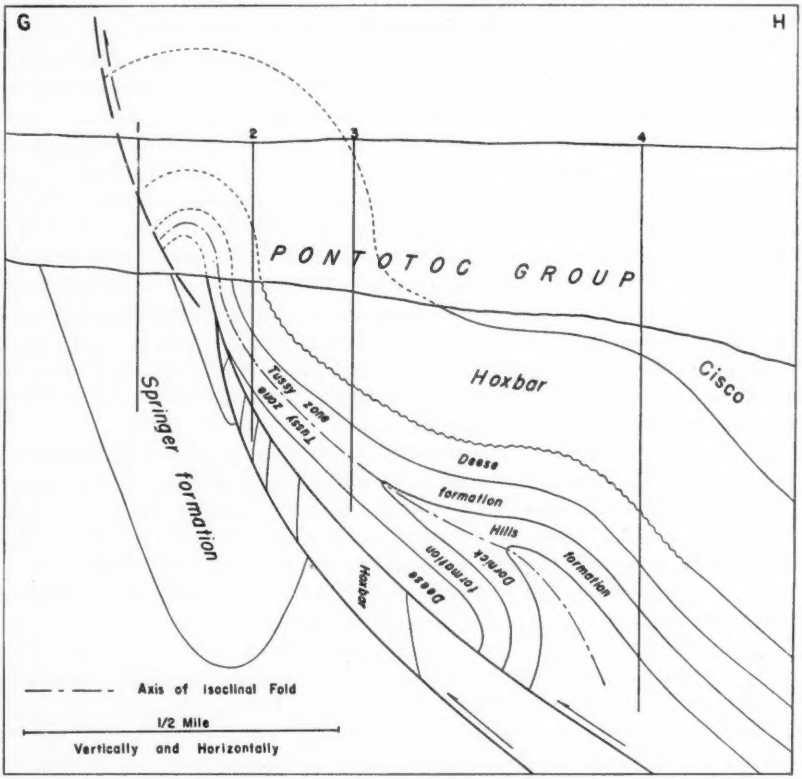


FIG. 13.—Northeast-southwest cross section GH (see Fig. 9). 1. Turner's Spears No. 1, SW. ¼ SE. ¼, SE. ¼, Sec. 15, T. 1 S., R. 5 W. 2. Gulf's Spears No. 1, SW. ¼, SW. ¼, SW. ¼, Sec. 14, T. 1 S., R. 5 W. 3. Gulf's Spears No. 2, SW. ¼, NW. ¼, SW. ¼, Sec. 14, T. 1 S., R. 5 W. 4. Sinclair-Prairie's Spears No. 3, SE. ¼, SE. ¼, NW. ¼, Sec. 14, T. 1 S., R. 5 W.

pressed into many small folds shown in plan on the geologic map of the unconformity (Fig. 9) and in cross sections.

Five mappable tear faults, transverse to the thrust fault, divide the eastern block into segments. Maximum displacement along these tears has been relatively small, probably a few hundred feet. Dips in the eastern block range from

20° to 45° on the crest of the anticline but steepen abruptly near the east margin of the pool where the beds are nearly vertical. There is no evidence to indicate at what depth this steep marginal dip levels off or reverses. Since the Velma pool is located on the axis of the Anadarko basin it can be assumed that the depth is great.

STRUCTURAL HISTORY OF VELMA POOL

The thinning and disappearance of the Springer sandstone and the spotty absence of the upper Deese formation show actual emergence and erosion immediately following the deposition of these formations.

The thickness of the pre-Virgilian Pennsylvanian in the Ardmore basin, 35 miles southeast of Velma, totals about 17,800 feet. The Gulf *et al.* Qualls No. 1, SW. $\frac{1}{4}$, NE. $\frac{1}{4}$, Sec. 23, T. 1 N., R. 7 W., a dry hole 12 miles northwest of Velma, is in the Deese formation at the total depth of 10,157 feet. If the 2,400 feet of Hoxbar formation in the Qualls well be compared with 4,000 feet near Ardmore, an estimate of the rate of regional northwestward thinning in the Ardmore-Anadarko geosyncline may be computed. Interpolating proportionally, the expected thickness of the pre-Virgilian (pre-Cisco) Pennsylvanian at Velma would be three times the actual thickness. Instead of thickening by steady accretion of sediment as at normal depths, the Velma section was often in a state of delicate balance between diastem and deposition.

Table II lists approximate thicknesses in feet of the pre-Cisco Pennsylvanian formations at the type section near Ardmore and thicknesses at the Velma pool (columns D and C). Also shown is the thickness of the Hoxbar in the Gulf's Qualls No. 1 (column A), a dry hole about 12 miles northwest of Velma. Interpolating proportionally, the expected thicknesses for Velma pool (column B) are derived. It is seen that the total expected thickness at Velma is three times the actual thickness (total, column B versus total, column C).

TABLE II

	Gulf's Qualls No. 1 A	*Velma* *Actual* B	*Expected* C	*Ardmore* D
Hoxbar	2,400	1,100	2,800	4,000
Deese	1,400 plus	725	5,600	8,000
Dornick Hills	Not penetrated	365	1,960	2,800
Springer	Not penetrated	2,150	3,100	3,000
		4,340	13,460	17,800

Constant subjection to the vagaries of surface currents can account for erratic behavior of individual beds associated with maintenance of identity of larger zones. Hence, three lines of evidence, (1) interformational unconformities, (2) abbreviated thickness, and (3) nature of sedimentation, indicate that the site of Velma pool persistently sank less than surrounding areas during Pennsylvanian time.

A persistently less negative and recurrently positive tendency throughout the Pennsylvanian was climaxed in post-Hoxbar time by orogenic deformation. Contrary to the ordinary conditions younger rocks are thrust upon older at Velma. This contingency eliminates the possibility that the Velma thrust occurred as simple shortening of an essentially horizontal section along a low-angle interface. The condition is typical of normal faulting and eliminates the possibility of proving the fault a thrust by demonstrating that a block of older beds lies on younger beds in normal succession. Nevertheless, the weight of evidence favors calling the fault a thrust for the following reasons.

1. Thrusting was an important phase of the Arbuckle orogeny in the Anadarko-Ardmore geosyncline. Dott[31] recognizes the presence of south-dipping thrust faults in the Arbuckle anticline and the Hunton-Tishomingo uplift. Lehman[32] describes similar thrust faults in the Mill Creek syncline of the Arbuckle Mountains. In Figure 2,[33] he shows thrust planes along which younger beds locally lie on older owing to folding in the autochthonous block and truncation by the thrust as at Velma. Thrusting is present in the Robberson pool, T. 1 N., R. 3 W., Garvin County.[34] The pre-Permian section there is folded into an anticline overturned and thrust toward the north. At the Eola pool, T. 1 N., R. 2 W., Garvin County, well data show that overturned Caney shale and Sycamore limestone (Mississippian) lie in thrust contact on Springer (Pennsylvanian). At the Cruce pool, T. 1 N., R. 5 W., Stephens County, 5 miles northwest of Velma on the same anticlinal trend, both Springer and Hoxbar have been found resting on a normal sequence of Cisco, Hoxbar, Deese, *et cetera*. This proves that thrusting occurred and dates the thrusting as intra- or post-Cisco. Van der Gracht places the Arbuckle orogeny in the mid-Cisco.

2. It can further be proved that thrusting occurred at the Velma pool. Skelly's Robberson No. 5, C., NW. 1/4, NE. 1/4, Sec. 35, T. 1 S., R. 5 W. (Fig. 9 within area of Dornick Hills, Sec. 35) enters the western block (autochthonous to the fault under discussion) at the pre-Permian unconformity. After penetrating 2,300 feet of Springer sand and shale, the well encounters a normal sequence of Sycamore limestone, Woodford chert, Henryhouse-Haragan and Chimneyhill limestone, Sylvan shale with dolomite at the base, and Viola limestone. At 7,228 feet the well again pierces the base of the Sylvan formation and repenetrates Sylvan dolomite and shale (in reverse order). The section is clearly overturned and the well intersects the axis of overturn at 6,820 feet in the Viola limestone. At 7,542 feet the well passes from overturned Sylvan shale into another normal sequence of Henryhouse-Haragan and Chimneyhill limestones, Sylvan shale and dolomite, and Viola limestone. This occurrence of Sylvan shale over the younger Henryhouse-

[31] Robert H. Dott, "Overthrusting in the Arbuckle Mountains, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 5 (May, 1934), pp. 598–602.

[32] Roy P. Lehman, *op. cit.*, pp. 203–06.

[33] *Ibid.*, p. 190.

[34] Robert Roth, "The Robberson Field, Garvin County," *Oklahoma Geol. Survey Bull. 40*, Vol. II (1930), p. 160.

Haragan and Chimneyhill limestones, the latter in normal order, proves the presence of reverse or thrust faulting. The well cuts the thrust plane at 7,542 feet. This fault is not the major fault referred to in this paper and shown on diagrams and maps. It occurs within the so-called western block (autochthonous to the "major fault" of this paper) and approximately 4,000 feet lower. To avoid confusion, the lower fault just described is referred to as fault "X." The orientation of fault plane "X" is unknown since it is not penetrated by other wells. Skelly's Robberson well No. 5 therefore proves that thrusting (fault "X") is present at Velma and that the thrust is associated with an overturned fold. Evidence for overturning in the Pennsylvanian formations of the eastern block is presented in the section entitled "Wells of Special Interest."

The analogy of (1) an overturned fold in early Paleozoic beds resting on a thrust plane (fault "X") and (2) a higher overturned fold in Pennsylvanian beds resting on a higher fault plane strongly suggests that the analogy is complete—that the "major fault" discussed in this paper is also a thrust. Also, inspection of cross section AB (Fig. 10) shows that wells 1, 2, and 3 define the fault plane as a curve with a steep upper part, gradually approaching the horizontal downward. This pattern, while not limited to thrust faults, certainly permits the interpretation.

Contention that fault "X" was formed during an earlier period of orogeny than the higher fault is invalid, since the Anadarko-Ardmore geosyncline did not undergo disturbance more severe than gentle regional warping from Cambrian to lower Pennsylvanian time.

3. Because younger beds lie in fault contact on older beds, it may be argued that the major thrust is a normal fault which occurred after folding of the complex Velma anticline. It has been shown previously that two examples of Cisco thrusting occur in the Velma-Cruce anticline. Since the fault in question cuts pre-Cisco formations but does not affect post-Cisco rocks (Pontotoc, Clearfork-Wichita) it also occurred in Cisco time. If this fault be a normal fault, then tension and compression must have been present in the same structural feature at about the same time.

4. If the eastern and western blocks had once been a single folded mass following the orogeny, the eastern block would have undergone essentially the same degree of erosional truncation as the western. This is not the fact. On the western block the Hoxbar is entirely missing, the Deese and Dornick Hills are preserved only as remnants in deep synclines and the greater part of the sub-Permian unconformity is developed on the Springer formation. On the eastern block erosional beveling has been comparatively slight. Figure 9 and all cross sections show that only in a belt about a mile wide along the east side of the fault has any beveling at all taken place. In the belt which did undergo beveling only part of the Hoxbar was removed from most of the area, and the Deese is exposed in small patches along anticlinal axes. However, if the eastern block had ever been dropped topographically lower than the western block, Cisco sediments would

have been deposited in the trough formed. At Velma the Cisco occurs on the eastern flank of the eastern block (Figs. 5, 12, 13).

5. Inspection of the four cross sections (especially EF, Fig. 12) shows that the response of the rocks in the eastern and western blocks to the compression which caused folding was essentially different. In the western block the entire Paleozoic section was pressed into folds of large amplitude with dips as steep as 70°. By comparison, the folds in the eastern block may be called shallow ripples with dips as steep as 45°. If these blocks had been folded as a single unit and later divided by normal faulting the structural pattern in each should be essentially similar. The existing pattern supports the contention that faulting was pene-contemporaneous with folding, allowing each block as a distinct unit to respond differently to the compressional forces of the Arbuckle orogeny.

All things considered, it appears probable that the major fault at Velma is a thrust fault, active in Cisco time, along which upward and westward encroachment of the eastern block occurred at a rate slower than the deformation of the western block. Erosion probably kept pace with structural movements so that the Velma anticline was never topographically very high. Surrounding Cisco sediments although copious are not coarse-grained.

To show how younger beds may lie in thrust contact on older, the following concept of the mechanics of faulting at Velma is presented. The center of the main Velma structure, possessing tendencies to rise throughout the Pennsylvanian, was compressed into tight overturned folds, subjected to overthrusting (fault "X"), and bowed upward into a complex arch. Continued compression and arching of the central mass produced a subsidiary arch on its east flank, which in turn was folded, and later overturned toward the axis of the main arch. Excessive slippage along planes in the shaly middle Deese zone permitted the formation of a recumbent fold at the north and south ends of the pool (Fig. 13, cross section GH). Progressive compression (1) attenuated and sheared the overturned limb of the subsidiary, flank anticline, (2) sheared the east side of the main arch, and (3) slowly thrust the eastern, subsidiary, folded block upward to its present position nearer, but still well below, the structural elevation of the main arch. Further compression squeezed the central part of the major uplift higher so rapidly that additional thrust movement along the oblique fracture did not materialize; instead, the upward movement of the central axis caused the hanging wall to lag behind and to assume the appearance of a normal fault. That the major compression affected the deep rocks of the main axis is also shown by the greater amplitude of the folds within it (southwest of the fault) in comparison with the much shallower folds in high beds (northeast of the fault).

Beveling concomitant with deformation reduced the topographic elevation of both arches and contributed to deposition of the Cisco formation in the residual basin east of the complex Velma anticline. Pontotoc and younger Permian sediments then buried the entire structure.

Because of the inclination of the thrust plane and the large vertical com-

ponent in the movement of the overthrust block, total horizontal displacement is estimated at a mile or two. Similar thickness and reasonably similar lithologic character of the Hoxbar formation of West Velma to that of Velma pool (Sec. 19 *vs.* Sec. 25) support the assumption of moderate original (prediastrophic) horizontal separation of the two areas. Late phase diastrophism (see section on regional structural history) was expressed as arching of the Permian cover to form the present surface structure.

WELLS OF SPECIAL INTEREST

Certain wells in the Velma pool are of special interest because they penetrate an overturned section, intersect a thrust plane, or indicate radical dip change.

Six wells pierce the thrust plane. (1). In the Gulf's Spears No. 1 (Well No. 2, cross section GH, Fig. 13), steeply dipping, shaly middle Deese and Tussy zone (overturned) lie in fault contact on vertical middle Deese and Tussy. The fault plane occurs between 2,000 and 2,150 feet. (2). In Skelly's Keukel No. 1 (Well No. 2, cross section AB, Fig. 10) Dornick Hills rests in fault contact on Mississippian-Caney shale. The well pierces the thrust plane at 3,560 feet. (3). In Skelly's Keukel No. 2 (Well No. 3, cross section AB, Fig. 10) the lower part of the Springer shale is missing. Upper Springer shale rests in thrust contact on Mississippian-Caney shale at 4,510 feet. (4). In Skelly's Doak Unit No. 3, NW. ¼, NE. ¼, NW. ¼, Sec. 36, T. 1 S., R. 5 W., Dornick Hills dipping 85° rests in fault contact on Mississippian-Caney shale. The well pierces the thrust plane at 2,995 feet. (5). In Skelly's Stephens No. 1, SW. ¼, NW. ¼, NE. ¼, Sec. 36, T. 1 S., R. 5 W., steeply dipping (overturned) Deese rests in fault contact on Mississippian-Caney shale. The well pierces the thrust plane at 3,385 feet. (6). In Skelly's Frensley "B" No. 2-D, NE. ¼, SW. ¼, SW. ¼, Sec. 25, T. 1 S., R. 5 W., F zone Hoxbar occurs at the base of the Pontotoc, lying on normal Culberson Deese. At 1,550 feet the well pierces the thrust plane and enters brownish gray, abundantly sideritic, micaceous Springer shale.

Four wells penetrate overturned sections. (1). The Gulf's Spears No. 1 enters shaly middle Deese at the base of the Pontotoc at 1,135 feet, penetrates the Tussy zone, intersects the axis of overturn at 1,695 feet and passes through the same section in reverse direction until it pierces the thrust sole. (2). The Gulf's Spears No. 2 (Well No. 3, cross section GH, Fig. 13) passes through a normal Hoxbar section dipping 45°, enters the Deese formation at 1,982 feet where the dip becomes much steeper, intersects the axis of overturn at 2,740 feet, and re-enters the Tussy zone of the Deese formation. Dip in the overturned limb is only 5°. (3). The Gulf's Hallmark No. 2, SW. ½, SE. ¼, NE. ¼, Sec. 15, T. 1 S., R. 5 W., passes from Pontotoc at 1,388 feet into Deese dipping 45°, intersects the axis of overturn at 1,920 feet, and repenetrates the same section overturned, dipping 82°. (4). Skelly's Stephens No. 1 penetrates a normal Hoxbar section, enters the Deese at 1,953 feet where the dip steepens, intersects the axis of overturn at 2,725 feet, and repenetrates most of the same section before cutting the thrust fault.

Mudge's Spears No. 8, NE. 1/4, NW. 1/4, NW. 1/4, Sec. 23, T. 1 S., R. 5 W., passes from Pontotoc into Deese at 1,120 feet and reaches total depth at 1,900 feet. At greater depth the well would probably encounter the overturned limb.

A few wells encounter anomalous thicknesses caused by peculiar structural features. In Mudge's Spears No. 9, SW. 1/4, NE. 1/4, NW. 1/4, Sec. 23, T. 1 S., R. 5 W., the Deese formation is 1,010 feet thick. Most of this section is shale, although an amount of sandstone and limestone equivalent to the normal thickness of the Tussy is present in the middle of the section as thin, widely separated beds. The Dornick Hills formation is 960 feet thick and has a somewhat similar appearance. This well is located in a tear-fault segment of the east block intermediate between the isoclinally folded north end of the pool and the less compressed central part. Actual thickening by slippage or flowage of shales toward the anticlinal crest plus apparent thickening caused by steep dip may be the cause.

In Skelly's Baker No. 1 and No. 2 (Wells 8 and 9, cross section CD, Fig. 11) the Hoxbar thickness is normal, but Deese and Dornick Hills thicknesses are as follows.

	No. 1	*No. 2*
Deese	745 feet	916 feet
Dornick Hills	1,066 feet	1,704 feet

This anomalous eastward thickening illustrates the abrupt structural plunge at the east margin of the pool. An extreme example is Carl Carter's Jones No. 1 (Well No. 9, cross section EF, Fig. 12). The Deese is 1,190 feet thick, and after penetrating 1,702 feet of Dornick Hills, the well is still in the upper part of the formation at the total depth, 6,500 feet. The dip must be nearly vertical.

Skelly's Davis No. 1, NW. 1/4, SE. 1/4, SE. 1/4, Sec. 24, T. 1 S., R. 5 W., and Skelly's Frensley "K" No. 1, SE. 1/4, SW. 1/4, SE. 1/4, Sec. 24, T. 1 S., R. 5 W., present similarly exaggerated Deese and Dornick Hills sections. In these and other adjacent wells, the lower E zone, the entire F zone of the Hoxbar and the Culberson zone of the Deese are entirely lacking, and the Hoxbar appears curiously telescoped. Elimination by normal faulting along the eastern belt of steep dip offers a partial explanation.

Skelly's Robberson No. 5, C., NW. 1/4, NE. 1/4, Sec. 35, T. 1 S., R. 5 W., demonstrates overturning and thrusting in the western block.

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GEOLOGICAL NOTES

REVISION OF STRATIGRAPHIC NAMES[1]

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GENERAL DISCUSSION

American geologists dislike to be confronted with unfamiliar stratigraphic names, preferring very naturally to use accustomed old terms. Like all human beings, they have resistance to being called on to learn something new. Habit and prejudice are strong.

The Stratigraphic Code (Ashley *et al.*, 1933, 1939) recognizes the principle that usage is a potent factor—even a controlling one—in nomenclature of rock units. Obviously, stability of stratigraphic names is an important aim of geologic science just as instability is to be avoided as a source of unending bother and confusion. By stability we mean both the retention of any used and useful stratigraphic name, and maintenance of its definition without change.

If we discard names which are widely used in the published record and well known to many geologists, there should be compelling reasons, because in abandoning previously used stratigraphic terms we are contributing to instability of nomenclature and are sacrificing valuable geological capital. Users of substitute new names, which assumably have meanings somewhat modified from the old, must not only become acquainted with new terminology and learn about the revised meaning, but always they must translate the old nomenclature into the new whenever and wherever they encounter it. Such is the case in every reference to papers dealing with the unit published before the date of change. Largely for this reason, judgment expressed in the Code favors retention of old names with the revision of meaning which is deemed necessary. Avoidance of confusion in meaning is a virtue of newly introduced names, but this virtue must be weighed against the loss involved in throwing away old names.

If research establishes the unsuitability of an old stratigraphic name, no matter how old or how much used, something has to be done. Geologic science can not stand still, chained unbreakably by the incomplete knowledge or faulty judgment of an earlier generation of geologic workers. First, however, there is need for proof—for determination beyond reasonable doubt—that formerly accepted application of a stratigraphic name is no longer "suitable." One geologist may become satisfied with the unfitness of the old term in its agreed meaning, or a half-dozen geologists may similarly become convinced, but the great majority of workers having interest in, or happening to know about, the stratigraphic features

[1] Manuscript received, September 13, 1948.

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concerned with the old and with proposed new usage may not at all understand or agree on need for change. Laws are lacking either to make publication of revised signification of the old name illegal, or to compel adoption by all geologists of the views held by a few. Of course, this lack of enforced agreement by legal statute is as it should be. The one geologist or the few may be unassailably right in concluding that old usage fails to take account of geological evidence having utmost importance. They may be right also in judging that either revision or discard of the old term is necessary. The majority may be ignorant or unconvinced, but nevertheless wholly wrong. Until there is unanimity of acceptance of need for change, with or without comprehension of pertinent evidence and of reasoning which support change, division is inevitable. A varying amount of confusion attends this division.

Next comes question of the proper course—that is, most desirable course—which proponents of change in stratigraphic nomenclature should pursue. Should they retain the old name and publish their own revised definition of it? Or, should they abandon the old name and publish a brand new one with accompanying definition? The Stratigraphic Code really does not help much in answering these questions. To adopt the course of trying to preserve an old stratigraphic name, in accordance with qualified recommendation of the Code, would be highly objectionable procedure if there is prospect that the revision will remain unaccepted by a sizeable number of geologists (whether majority or minority of these concerned does not matter). It is much better, in such case, to introduce a new name, abandoning the old. This would result in minimum difficulty, for those who accept the new terminology and those who insist on using the old are both understood. Confusion is avoided, but at expense of adding to the number of used stratigraphic names and at a sacrifice by many of the familiar old name which they no longer employ.

If there is reason to expect that all but a few geologists will shortly adopt the revised definition of an old stratigraphic name, change should be effected by revision rather than substitution. Hope that a revised term may become accepted is not enough. Hopes are too often unrealized. A geologist may mislead himself readily, either by overrating the weight of evidence which he has found or over-estimating the cogency of his own arguments. He may be misguided by the ready acceptance of his views by a few friends. How can the geologist assure himself of reasonable probability that revision of a stratigraphic name proposed by him will be accepted generally before he dies? One good way is to make tests of friendly (and unfriendly) geological judgments as widely as possible before he publishes. This can be done through oral presentation of a paper at local, regional, and national meetings. It can be done advisedly also by correspondence, particularly with geologists best acquainted with the rocks concerned and best versed in sound stratigraphic principles. Consultation with representative groups of able stratigraphic workers such as the Association Committee on Geologic Names or the American Commission on Stratigraphic Nomenclature, and with the Federal and State geological surveys is likely to be helpful. In general, there is no need to keep

silence before going on record in print lest someone steal the "credit" of being first to publish a revision of stratigraphic nomenclature. Without too much time or trouble it should be possible in these ways to estimate fairly the proper course of action, whether to propose redefinition of an old name or to introduce a new one.

NORTHERN MID-CONTINENT INTER-STATE AGREEMENT ON REVISION OF STRATIGRAPHIC NAMES

In connection with the foregoing discussion, an agreement by the State geological surveys of Iowa, Kansas, Missouri, Nebraska, and Oklahoma, adopted in May, 1947, is of interest. This agreement is supplemental to acceptance by the surveys mentioned of classification and nomenclature of Pennsylvanian rocks which may be applied uniformly on opposite sides of boundaries between the states concerned (Moore, 1948). It is recognized that in treating the definition and name of a rock unit which is known to extend from its type locality, in Kansas, for example, into one or more neighboring states, these latter have a proprietary interest. They are properly concerned about any proposed change of meaning in application of such a stratigraphic name, because the name is employed in designating a rock unit within the limits of their own states. If the Kansas Geological Survey should decide that the boundaries of the Shawnee group (named from Shawnee County, Kansas) should be altered, the name being retained with revised stratigraphic meaning, the Missouri, Nebraska, and other concerned State surveys, which class some of their local formations as belonging to the Shawnee group, would have three possible courses: (1) acceptance of the Kansas revision, which would provide uniform inter-state classification and nomenclature if all States agreed; (2) retention of Shawnee group as previously defined, which would result in discordant use of the same name in different areas; or (3) substitution of a new name for the rocks previously called Shawnee in Missouri, Nebraska, *et cetera*. This makes clear that unilateral action in making stratigraphic revisions is undesirable.

The agreement of northern Mid-Continent State geological surveys to forego revision of any rock unit having inter-state distribution does not freeze classification and nomenclature in any of these states. Proposal may be made for acceptance by all concerned of a revision of any unit and, if all agree, this is sufficient to permit retention of the old name with a changed stratigraphic meaning. Alternatively, any State may modify the name and definition of any unit by introducing new terms.

The objectives of the inter-state agreement concerning revision of stratigraphic names are of general interest. It seems desirable, therefore, to publish the text of the agreement memorandum, which follows.

PRINCIPLES AND POLICIES RELATING TO STRATIGRAPHIC NOMENCLATURE AFFECTING INTER-STATE USAGE

Whereas, it is recognized that:

(a). Boundaries of natural stratigraphic provinces mostly do not coincide with State lines.

(b). Stratigraphic nomenclature judged most satisfactorily to serve purposes of description and mapping should be governed by objective geologic observations rather than political boundaries or other non-geologic considerations.

(c). Although each State Geological Survey is responsible for stratigraphic nomenclature adopted as official usage within its own state, each Survey has obligation to neighboring states into which named rock units extend. (1′) This obligation primarily consists in preserving stability of nomenclature of interstate rock units that are based on sections within the borders of its own state. (2′) Also, the obligation calls for avoidance of usage by a Survey of stratigraphic terms based on sections outside of the state unless this usage conforms to that recognized by the Survey of the state wherein the type sections are located.

(d). Uniformity of stratigraphic usage contributes to clarity of understanding by all concerned.

Therefore, it is agreed that:

1. No emendation of stratigraphic terms in inter-state use shall be made or accepted unless the concerned State geological surveys express agreement on the nature of such proposed emendation.
2. When emendation of a stratigraphic term in inter-state use is agreed to by concerned State geological surveys, statement of reasons for such emendation shall be published, and the Surveys thereafter shall severally employ the emended stratigraphic term only in the revised sense.
3. If any State Survey concludes that proposed emendation of a stratigraphic term applied to rocks within its state is undesirable, whether the term is based on a section within or outside of the state, emendation shall be avoided except under circumstances judged to be compelling, and a Survey or surveys desiring a different classification shall then adopt previously unused stratigraphic terminology for the unit or units concerned.
4. In case of synonymous terms, that having priority shall be adopted and the junior synonym shall be dropped.

REFERENCES

Ashley, G. H., et al., 1933, "Classification and Nomenclature of Rock Units," *Bull. Geol. Soc. America*, Vol. 44, pp. 423–59; also *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, pp. 843–63.

———, 1939, "Classification and Nomenclature of Rock Units," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, pp. 1068–88.

Moore, R. C., 1948, "Classification of Pennsylvanian Rocks in Iowa, Kansas, Missouri, Nebraska, and Northern Oklahoma," *ibid.*, Vol. 32, No. 11 (November, 1948).

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 10 (OCTOBER, 1948), PP. 1984-1988

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

GUIDEBOOK, THIRD ANNUAL FIELD CONFERENCE, WIND RIVER BASIN, WYOMING, 1948, BY WYOMING GEOLOGICAL ASSOCIATION

REVIEW BY T. C. HIESTAND[1]
Casper, Wyoming

Guidebook, Third Annual Field Conference, Wind River Basin, Wyoming, August 14-19, 1948. 202 pp., 40 geologic and structural maps; 10 plates and figures, stratigraphic and electric-log charts and columns; 1 pl., physiographic block diagram; 2 pp. photos, 1 pl., microfossils; 1 table of correlations; 4 structural cross sections. Heavy grained paper cover, plastic binder, 8.5×11 inches. Published by the Wyoming Geological Association. For sale at Casper, Wyoming, Box 545. Price, $4.25.

The impressive volume continues in the series commenced in 1946, on southeastern Wyoming, and followed in 1947, on the Bighorn Basin. And it eloquently reflects leadership of the Conference committee: general chairman, Philip W. Reinhart; editor, Jed B. Maebius; road-log editor, Paul W. Netterstrom; registration and caravan, F. Howard Brady, chairman; advertising, Charles S. Agey, chairman.

Road Logs of Scheduled Trips include three daily trips radiating from Lander. Geological framework of the intermontane basin is placed under examination by means of the fifteen stops, supplemented by brief lectures at each stop. *Exit Road Logs* include five principal routes leading out of the basin and thus offer a convenient guide for private trips as well as those more formally organized for school or company groups.

Papers on Regional Geology, 130 pp., discuss the subjects of structure, stratigraphy, and sedimentation; and are mentioned by title and author, as follows.

The Structural Pattern of the Wind River Basin, Wyoming, by D. L. Blackstone, Jr., comprehensively discloses results of latest studies, stimulates thinking of the structural student, and challenges the exploration geologist. The basin separates the Rockies into northern and southern ranges. Varied structural patterns are discussed according to the lithologic units of the less competent Mesozoic, the more competent Paleozoic formations, and properties of the crystalline crust. The principal deformation, the several phases of the Laramide, followed deposition of marine Cretaceous. Late Cretaceous and Tertiary depositional history was influenced by this deformation. The author observes that an early subsidence on the eastern margin of the basin influenced formational thicknesses and tectonic features.

Summary of Paleozoic Stratigraphy of the Wind River Basin, by Horace D. Thomas; *Mesozoic Stratigraphy of the Wind River Basin*, by J. D. Love; *Tertiary Rocks in the Northeastern Part of the Wind River Basin*, by Harry A. Tourtelot; *The Morrison and Cloverly Formations*, by Raymond E. Peck and Carl C. Reker. These four contributions are excellently illustrated with charts and maps. And they serve to introduce the current knowledge of the stratigraphy to the visitor as well as to provide a ready reference to the resident geologists. Thomas recognizes problems of "age" correlations in two classes: first, between discontinuous lithologic units such as occur in Cambrian, Devonian and Permian, and second, within continuous units such as the Tensleep and Casper formations. Love constructively attacks a host of problems, many of which have to do with systemic

[1] Division geologist, Cities Service Oil Company. Review received, September 20, 1948.

boundaries. He finds a discrepancy in "age" correlation within the Frontier formation between the Wind River Basin and the type locality in southwestern Wyoming. He defers comment on post-Frontier names and correlations until more field work has been done in the basin. Tourtelot has enthusiastically studied continental Tertiary formations in recent years with the expectation that the knowledge obtained would be of prime importance in comprehending the Rockies. The emphasis on the basins is thus following the older emphasis on the mountains. Peck presents the microfaunas of Cloverly and Morrison to assist in separating the two formations which are commonly undivided over large areas. Seven lithologic units are numbered which are recognized in the field but can not be separated readily into either Cloverly or Morrison formations of respective type localities.

Regional Relationships of Wind River Basin Sediments, by George R. Downs. The author presents a total of 14 regional maps in series, each of which extends from the Canadian shield on the northeast to the Cordilleran geosynclincal belt on the west. These maps illustrate changes in regional environment which controlled deposition of sediments from Later Proterozoic to Upper Cretaceous strata. On each map the site of the present Wind River Basin is indicated, even though the text explains the basin was not present until close of the Cretaceous. Thus the broad influences were spread over the central part of the continent, modified by local features at times such as pre-Pennsylvanian highlands in Colorado.

Papers on Oil and Gas Fields, 51 pp., describe the geology pertinent to 19 oil and gas fields within and adjacent to the basin, oil and gas production, and discovery dates. They are mentioned by title and author as follows.

The Lander-Hudson Oil Field, Fremont County, Wyoming, by E. W. Krampert; *Dallas Field, Fremont County, Wyoming*, by E. W. Krampert; *Winkleman Dome, Fremont County, Wyoming*, by W. S. McCabe and C. L. Walker. These fields are shallow in depth and located along the foot of the Wind River mountains. *Sand Draw Gas and Oil Field, Fremont County, Wyoming*, by E. W. Krampert (also called Big Sand Draw field); *The Beaver Creek Field, Fremont County, Wyoming*, by M. D. Hubley. These two fields are deeper and located in south-central part of the basin. *Steamboat Butte Oil Field*, by H. E. Barton; *Circle Ridge and Maverick Springs Oil Fields, Fremont County*, by W. G. Olson. These fields are at the center and northern rim of the basin, respectively. *Résumé of the Oil and Gas Structures Immediately Adjacent to the Southeastern Margin of the Wind River Basin*, by H. E. Summerford. This résumé of 11 oil and gas fields illustrates the regional relationships and outlines the characteristics of each field in the text.

This interesting group of papers presents stratigraphic columns and electric logs, surface and subsurface structural contour maps and cross sections, to describe "typical" fields. And yet in no two fields is the geology or occurrence of oil and gas duplicated Subsurface faulting and axial shift at Sand Draw are important; a small igneous dike on the west flank of Winkleman Dome is not found to be significant; thrusting brings saturated Phosphoria limestone to the "grass roots" at Circle Ridge; and at West Poison Spider production in the Wall Creek sands at depth of 14,305 feet, a world record, is located but 4 miles west of outcrops of the same formation along a thrust belt.

Production of Crude Oil and Gas in the Wind River Basin, Wyoming, compiled by Petroleum Information, Inc., tabulates the annual oil production by fields, gives oil gravity, dates of discovery, and number of producing wells at present. The cumulative gas production through 1947, is given by fields, and discovery date of each field is furnished. The oil gravity ranges from 16° to 41° A.P.I. The basin district is an important gas reserve.

Business and Professional Directory, 4 pp., is the only advertising.

Special Maps (*in pocket at back of book*) are mentioned by title and author as follows: *Geologic Map and Structure Section, Lander Area*, by R. E. Peck, compiled on aerial-photo base: *West End of Laramie Range*, by F. C. Sims, is locality at west end of Casper

Mountain; *Beaver Creek-South Sheep Mountain Area*, by P. L. Gooldy, is locality southeast of Lander; *Red Canyon Area*, by E. J. McKay, is locality immediately west of that mapped by Gooldy, and immediately south of that mapped by Peck. These local maps are especially valuable at present, both to exploration geologists and to the U. S. G. S. in its efforts to publish a geologic map of Wyoming in the near future. *Photogeologic Map of Maverick Springs Area*, by H. C. Rea. *Correlation Charts, Mesozoic Stratigraphy*, by J. D. Love, includes Fig. 1–4, and ties measured surface sections with sample and electric logs of wells; part is from unpublished, forthcoming report by R. M. Thompson.

In the series of Wyoming Geological Association guidebooks, the first two are already out of print. The present volume, a condensed summary of geological knowledge pertaining to the Wind River Basin, is made possible by enthusiastic work of 45 members of the Wyoming Geological Association, by splendid counsel and contributions of geologists with the U. S. Geological Survey and universities of Wyoming and Missouri. The annual field conference in Wyoming has become convention-size with evening technical papers and the guidebook is a symposium useful to schools, petroleum producers, geophysical, drilling and well-service organizations.

RECENT PUBLICATIONS

ARABIA

* *Summary of Middle East Oil Developments*, 2d ed. (1948), prepared by Arabian American Oil Company. 48 pp., 8×10.5 inches, folded map in colors, listing companies with areas of concessions and permits. Includes map of world showing petroleum reserves (70,400,000,000 barrels).

**Arabian Oil and the World Oil Shortage*, prepared by the Arabian American Oil Company ("Aramco"), 711 Fifth Avenue, New York (1948). 48 pp. 8×10.5-inch cardboard weight paper, display type, printed in 2 columns, lithographed in color. Statistics and charts on supply and demand, reserves, history, operations. Plastic spiral bound.

BRAZIL

*"Classification of the Gondwanic Rocks of Paraná, Santa Catarina, and Rio Grande do Sul," by Mackenzie Gordon, Jr. *Brazil Divsão de Geol. e Min. Notas Prelim. e Estudos*, Num. 38a (Rio de Janeiro, July, 1947). 19 pp.

CANADA

"A Middle Triassic (Anisian) Fauna in Halfway, Sikanni Chief, and Tetsa Valleys, Northeastern British Columbia," by F. H. McLearn. *Geol. Survey Canada Paper 46–1*, 2d ed. (Ottawa, July, 1948). Text and 12 fossil pls.

"Physiography of the Canadian Cordillera, with Special Reference to the Area North of the Fifty-Fifth Parallel," by H. S. Bostock. *Canada Geol. Survey Mem. 247* (Ottawa, 1948). 106 pp., 32 pls. (aerial photographs), folded map in colors, in pocket, showing physiographic subdivisions). Price, $0.25.

COLORADO

"Geology of the Egnar-Gypsum Valley Area, San Miguel and Montrose Counties, Colorado," by W. L. Stokes and D. A. Phoenix. *U. S. Geol. Survey Prelim. Map 93*, Oil and Gas Inves. Ser. (August, 1948). Sheet, 38×41 inches. Map, sections, and text. For sale by Director, U. S. Geological Survey, Washington 25, D. C. Price, $0.50.

ETHIOPIA

*"Geology of Ethiopia Being Developed by Sinclair in Exploring Concession," by

Hall Taylor. *Oil and Gas Jour.*, Vol. 47, No. 15 (Tulsa, Oklahoma, August 12, 1948), pp. 48–51; 1 stratigraphic section, 4 photographs.

FRANCE

*"Les recherches de pétrole dans le Bassin d'Aquitaine" (Search for Petroleum in Aquitaine Basin), by P. Maugis. *Bull. Assoc. Française des Techniciens du Pétrole*, No. 70 (August, 1948), pp. 19–43; 7 figs. Redaction et Administration, 44, Rue de Rennes, Paris 6.

GENERAL

"Geophysical Abstracts 132, January-March, 1948", by V. L. Skitsky and S. T. Vesselowsky. *U. S. Geol. Survey Bull. 959-A* (1948). 85 pp. Supt. Documents, Govt. Printing Office, Washington 25, D. C. Price, $0.25.

"Publications of the Geological Survey." *U. S. Geol. Survey* (1948). 322 pp. Free on application to Director, Geological Survey, Washington 25, D. C.

"New List of Map Symbols," prepared by Map Symbol Committee, E. N. Goddard, chairman. *U. S. Geol. Survey Spec. Pub.* (1948). 6 sheets. Free on application to Director, Geological Survey, Washington 25, D. C.

"Rock Color Chart," prepared by Rock-Color Chart Committee, E. N. Goddard, chairman. *U. S. Geol. Survey Spec. Pub.* (1948). 6 charts and explanation, with mask and 2 figs., size 5×7.5 inches. For sale by National Research Council, Division of Geology and Geography, 2101 Constitution Avenue, Washington 25, D. C. Price, $5.50.

*"Surface Geology Beneath the Sea," by J. L. Chase. *Petrol. Engineer*, Vol. 19, No. 12 (Dallas, Texas, August, 1948), pp. 102–12; 8 figs.

Sequence in Layered Rocks, by Robert R. Shrock. 483 pp., 650 drawings and photographs. 6.25×9.5 inches. McGraw-Hill Book Company, Inc., 330 West 42d Street, New York 18, N. Y. Price $7.50.

*"Is Your Well Still Drilling Granite Wash or Have You Reached Solid Granite?," by Charles J. Deegan. *Oil and Gas Jour.*, Vol. 47, No. 18 (Tulsa, September 2, 1948), pp. 84, 87, 88; 6 figs.

*"Review of Petroleum Geology in 1947," by F. M. Van Tuyl, W. S. Levings, and L. W. LeRoy, with the cooperation of J. H. Johnson, R. C. Holmer, and H. E. Stommel of the Faculty of the Colorado School of Mines, and other leaders in the fields of geology, geophysics, and petroleum engineering. Sponsored by the research committee of the A.A.P.G. *Quar. Colorado School of Mines*, Vol. 43, No. 3 (Golden, July, 1948). 334 pp. Includes a bibliography of 3,500 listings. Department of Publications, Colorado School of Mines, Golden, Colorado. Price, $3.00, postpaid.

*"Discovery of Oil Structures by Aerial Photography," by Bernard M. Bench. *Oil and Gas Jour.*, Vol. 47, No. 17 (Tulsa, August 26, 1948), pp. 98–100, 146–52; 5 figs.

*"Why Study Geology—Covering Old and New Ground," by M. M. Leighton. *Illinois Geol. Survey Cir. 140* (Urbana, 1948). 5 pp. Reprinted from *School Science and Mathematics*, Vol. 48, No. 1 (1948), pp. 34–39. Radio address presented over KODI, Cody, Wyoming, Thursday, August 7, 1947, on the occasion of the geological field conference in the Big Horn Basin, under the sponsorship of the University of Wyoming, Wyoming Geological Association, and the Yellowstone-Big Horn Research Association, and with Fellows of the Geological Society of America as special guests.

*"Careers in Geology," prepared by Don Carroll, Louis Ray, and Charles H. Behre, Jr., chairman, committee on advisory pamphlet for geology students, Division of Geology and Geography, National Research Council. *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 32, No. 6 (June, 1948), 1193–94. Part of the annual report of A.A.P.G. committee on applications of geology, Kenneth K. Landes, chairman, 1947, and R. A. Stehr, chairman, 1948. Copies free by writing to A.A.P.G., Box 979, Tulsa 1, Oklahoma.

*"Addresses Delivered at the Twenty-Fifth Annual Convention, National Oil Scouts and Landmen's Association, Denver, Colorado, June 3, 4, 5, 1948." 12-page, 8.25×10.75-inch pamphlet. Contains 3 papers.

"President's Address," by Howard R. Brooks.

"Who Finds Oil," by Ira Cram.

"Bureau of Mines Oil-Shale Program," by Russell Cameron and Homer Ballinger.

GERMANY

*"Geologische Probleme der Erdölsuche in Nordwestdeutschland" (Geological Problems of Petroleum Exploration in Northwestern Germany), by Alfred Bentz. *Erdöl und Kohle*, Vol. 1, No. 1 (1948). 15 pp., 1 map. Industrieverlag von Hernhaussen, K-Ges., Hamburg 36.

MONTANA

"Marine Jurassic Formations of Montana," by R. W. Imlay, L. S. Gardner, C. P. Rogers, Jr., and H. D. Hadley, *U. S. Geol. Survey Prelim. Chart 32*, Oil and Gas Inves. Ser. (August, 1948). Sheet 40×64 inches. For sale by Director, U. S. Geological Survey, Washington 25, D. C. Price, $0.50.

OHIO

"Map of Berea Sand of Southeastern Ohio, Northern West Virginia, and Southwestern Pennsylvania," by James F. Pepper and others, and revised by David F. Demarest and Wallace de Witt, Jr. *U. S. Geol. Survey Prelim. Map 89*, Oil and Gas Inves. Ser. (August, 1948). Sheet 41×60 inches. For sale by Director, U. S. Geological Survey, Washington 25, D. C. Price, $0.60.

TURKEY

*"Türkiye Cenup Doğu Bölgeleri Stratigrafisi" (Stratigraphy of Southeastern Turkey), by Cevat E. Tasman. *Maden Tetkik ve Arama Enstitüsü Mecmuasi "M.T.A." 38* (Ankara, 1948 sayisindan), pp. 69–77; 1 chart. English summary, p. 77.

**Bull. Geol. Soc. Turkey*, Vol. 1, No. 2 (March, 1948). 135 pp., illus. 6.75×9.5 inches. Printed by Kenan Matbaasi, Istanbul. Contains in part the following.

"Upper Cretaceous on the Peninsula of Samanli," by Galip Otkun. Pp. 1–3 in Turkish; 4–5 in French. 1 map.

"Geological Observations in the Hazru-Eğil Region (Northeast and North of Dryarbakir)," by W. Chazan. Pp. 6–7 in Turkish; 8–13 in French.

"Age of Detrital Deposits in the Plains of Kasaba and Elmali," by Talip Yücel. Pp. 14–19 in Turkish; 20–24 in French.

"Terrain in Carboniferous Basins of Northwestern Anatolie," by Fl. A. Charles. Pp. 25–26 in Turkish; 27–38 in French.

"Cretaceous and Nummulitic Foraminifera of Turkey," by Atife Daci. Pp. 51–69 in Turkish; 70–71 in English.

"Geology of Lignite Beds in Region of Erzurum," by E. Lahn. Pp. 72–78 in Turkish; 79–83 in French.

"Geological Bibliography of Turkey," by E. Lahn. Pp. 96–98 in Turkish; 89–100 in French. Bibliography, pp. 101–35 (519 entries).

WYOMING

"Aeromagnetic Profiles of the Big Horn Basin." *U. S. Geol. Survey* open files. Profiles and short text may be examined at Room 1033 library, U. S. Geological Survey and Room G-232 F. W. A. Building, Washington, D. C.; 315 Federal Building, Billings, Montana; Science Hall, University of Wyoming, Laramie, Wyoming; and office of Conservation Branch, Department of Interior, 305 Federal Building, Casper, Wyoming.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 10 (OCTOBER, 1948), PP. 1989-1999

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* Terms of individuals expire at the close of the annual meeting in March of the year indicated, unless another month is shown.

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Robert J. Riggs	Paul H. Price	F. W. Rolshausen
F. M. Van Tuyl	W. H. Twenhofel	Robert J. Seale
W. A. Waldschmidt	Claude E. ZoBell	Georges Vorbe
Oscar G. Wilhelm		

GEOLOGIC NAMES AND CORRELATIONS COMMITTEE

Henry J. Morgan, Jr. (1951), *chairman*, Atlantic Oil and Refining Company, Dallas, Texas

1949	1949	1950	1951
Charles F. Bassett	Horace G. Richards	C. I. Alexander	M. G. Cheney
A. E. Brainerd	G. D. Thomas	Stuart K. Clark	E. J. Combs
Ross L. Heaton	H. D. Thomas	W. J. Hilseweck	Robert H. Dott
Grover E. Murray	Robert O. Vernon	P. H. Jennings	Herman Gunter
	L. E. Workman	Wayne V. Jones	Raymond C. Moore
		W. Armstrong Price	
		H. A. Tourtelot	

SUB-COMMITTEE ON CENOZOIC

Grover E. Murray (1949), *chairman*, Magnolia Petroleum Company, Jackson, Mississippi

Robert O. Vernon (Atlantic Coast)
———— (Pacific Coast)
———— (Eastern Gulf Coast)
Philip H. Jennings (Western:Gulf Coast)
Harry A. Tourtelot (Rocky Mtns. and Great Plains)

SUB-COMMITTEE ON MESOZOIC

G. D. Thomas (1949), *chairman*, Shell Oil Company, Inc., Shreveport, Louisiana

C. I. Alexander (Gulf Coast)
Ross L. Heaton (Rocky Mtns. and Great Plains)
Horace G. Richards (Atlantic Coast)

SUB-COMMITTEE ON PALEOZOIC

L. E. Workman (1949), *chairman*, Illinois Geological Survey, Urbana, Illinois

H. D. Thomas (Rocky Mtns. and Great Plains)
Stuart K. Clark (Mid-Continent)
E. J. Combs (Eastern Interior)
R. V. Hollingsworth (Southwestern U.S.A.)
Charles F. Bassett (Appalachian Region)

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Arthur E. Brainerd
M. G. Cheney
Robert H. Dott
Herman Gunter
W. J. Hilseweck
Raymond C. Moore
W. Armstrong Price

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R. A. Stehr (1949), *chairman*, Seaboard Oil Company, Dallas, Texas

1949	1950	1951
E. M. Baysinger	Don L. Carroll	
Charles J. Deegan	Stanley G. Elder	
L. B. Herring	Leo R. Fortier	
	Thomas A. Hendricks	
	W. T. Nightingale	
	W. T. Schneider	

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R. Dana Russell, *ex officio*, president of S.E.P.M.
L. L. Nettleton, *ex officio*, president of S.E.G.

1949	1950	1951
Russell S. McFarland	Frank R. Clark	
Raymond F. Baker	Alfred H. Bell	
W. C. Spooner	A. E. Brainerd	

COMMITTEE ON STATISTICS OF EXPLORATORY DRILLING

F. H. Lahee (1950), *chairman*, Sun Oil Company, Box 2880, Dallas, Texas
Graham B. Moody (1951), *vice-chairman*, Standard Oil Co. of California, San Francisco

1949	1950	1951
J. A. Brown	Walter L. Ammon	Kenneth Cottingham
Coleman D. Hunter	A. H. Bell	C. W. Donnelly
Robert C. Lafferty, Jr.	G. P. Crawford	George C. Grow, Jr.
D. J. Munroe	R. J. Cullen	Charles H. Row
T. F. Petty	W. S. McCabe	A. N. Sharrick
Glenn C. Sleight	H. J. McLellan	F. B. Stein
Paul H. Umbach	R. M. Wilson	Paul Weaver
C. W. Wilson		

DISTINGUISHED LECTURE COMMITTEE

Fred H. Moore (1949), *chairman*, Magnolia Petroleum Company, Roswell, New Mexico

1949	1950	1951
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John F. Ferguson	H. T. Morley	

SPECIAL COMMITTEES

COMMITTEE ON BOY SCOUTS LITERATURE

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Max W. Ball	Carey Croneis	W. T. Thom, Jr.
Hal P. Bybee	E. C. Dapples	Russell M. Tripp
Don L. Carroll	G. W. Pirtle	Martin Van Couvering

EDUCATION COMMITTEE

Roy R. Morse, *chairman*, Shell Oil Company, Box 2099, Houston, Texas

Stuart K. Clark	Ronald K. DeFord	Theron Wasson
Morgan J. Davis	Henry V. Howe	

COMMITTEE ON NATIONAL RESPONSIBILITY OF GEOLOGISTS

Colonel O. F. Kotick, *chairman*, Army-Navy Petroleum Board, Room 2830 T-3, Navy Building, Washington, D. C.

Max W. Ball	Carle H. Dane	Charles T. Jones
Olin G. Bell	A. Rodger Denison	C. Gill Morgan
Don L. Carroll	James Gilluly	Hubert G. Schenck
Arthur A. Curtice	Benjamin F. Hake	W. T. Schneider
Drexler Dana	William B. Heroy	Edmund M. Spieker

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Ralph G. Blynn, Tulsa, Okla.
Shirley L. Mason, Frank A. Bruner, R. A. Weingartner
Arthur Newcomb Dusenbury, Jr., Caracas, Venezuela, S. A.
F. A. Sutton, James S. Cullison. G. Zuloaga
Norman Oren Edge, Wewoka, Okla.
Charles E. Decker, Carl A. Moore, V. E. Monnett
Eugene Wilson Germany, Dallas, Tex.
Claude C. Albritton, Jr., E. B. Germany, S. M. Aronson
Marie Gramann, Corpus Christi, Tex.
H. E. Menger, Glen Petrick, Robert N. Kolm
Daniel Stanley Johnston, Los Angeles, Calif.
Frank S. Parker, Loyde H. Metzner, A. W. Gentry
Howard Feighner Johnston, Newark, Ohio
E. T. Heck, R. C. Tucker, David B. Reger
Frank Herman Kratka, Jr., Rangely, Colo.
Claude E. Leach, F. W. Hertel, Harry Whaley
Nicolas Lanyi, Dallas, Tex.
John W. Clark, William W. Clawson, Fred E. Joekel
Erich M. Schlaikjer, Forest Hills, N. Y.
John H. Maxson, David B. Miller, Chester Stock
Walter Vernon Searight, Rolla, Mo.
Robert P. McNeal, John C. Frye, Charles Ryniker
Baxter Lile Smith, Jackson, Miss.
J. M. Hansell, James A. Waters, David C. Harrell

FOR ASSOCIATE MEMBERSHIP

James McCoin Allison, Ellery, Ill.
Don L. Frizzell, Hal P. Bybee, H. B. Stenzel
Earl Bowen Austin, Jr., Dallas, Tex.
M. E. Wilson, Ellis W. Shuler, Claude C. Albritton, Jr.
Henry Lee Berryhill, Jr., Charlotte, N. C.
John W. Huddle, E. Willard Berry, J. H. Watkins
Thomas Robinson Beveridge, Monmouth, Ill.
A. C. Trowbridge, Allen C. Tester, A. K. Miller
Clyde Andrew Brooke, Jr., Lake Charles, La.
Frank Bruner, Caldwell Starkey, W. B. Neill
Eugene R. Brownscombe, Dallas, Tex.
H. V. Tygrett, W. Dow Hamm, Edgar Kraus
Sylvia Clementine Cearley, Midland, Tex.
M. A. Stainbrook, Raymond Sidwell, Leroy T. Patton
Rodney Guild Colvin, Los Angeles, Calif.
A. S. Holston, Donald M. Davis, Peter H. Gardett

Joseph L. Cramer, Albuquerque, N. M.
J. C. Johnston, V. G. Hill, H. H. Kister
Edwin Philip Davis, San Antonio, Tex.
W. Dow Hamm, Robert N. Kolm, Edwin D. McKee
William C. Durham, Jr., Nowata, Okla.
F. A. Melton, Keith M. Hussey, Carl A. Moore
David George Easker, Cedar Rapids, Iowa
A. C. Trowbridge, Allen C. Tester, A. K. Miller
Ralph Harold Fellows, Midland, Tex.
Dan E. Holland, E. H. Powers, M. E. Upson
Kenneth Dunn Fore, Mexia, Tex.
Keith M. Hussey, F. A. Melton, Carl A. Moore
Eldon Fredyrick Frazey, Oil Hill, Kan.
A. K. Wilhelm, George F. Berry, Jr., Lindsey G. Morgan
Martha Jane Gallagher, Los Angeles, Calif.
U. S. Grant, James Gilluly, John C. Crowell
Robert Wynn Grayson, Houston, Tex.
Hal P. Bybee, G. K. Eifler, Jr., Fred M. Bullard
John F. Harris, Casper, Wyo.
A. N. Murray, C. V. Sidwell, W. H. Twenhofel
Richard Armstrong Higgins, Cut Bank, Mont.
W. A. Milek, J. H. McCourt, J. E. Hupp
William David Johnson, Jr., Moorhead, Mont.
John W. Huddle, E. Willard Berry, J. H. Watkins
John Edward Johnston, Bradford, Pa.
John W. Huddle, E. Willard Berry, J. H. Watkins
Fred B. Jones, Jr., Ardmore, Okla.
Charles Ryniker, M. P. White, Carl A. Moore
John Martin Kershner, Duncan, Okla.
Keith M. Hussey, Hugh D. Miser, V. E. Monnett
Frank Edward Kottlowski, Bloomington, Ind.
John B. Patton, Ralph Esarey, Carlton J. Leith
Louis Lafayette McCormick, Jr., Destrehan, La.
H. V. Howe, Richard J. Russell, H. N. Fisk
John Chester Mickelson, Iowa City, Iowa
Allen C. Tester, A. C. Trowbridge, A. K. Miller
Henry Francis Nelson, Austin, Tex.
John T. Lonsdale, H. B. Stenzel, M. L. Thompson
Walter Dan Paterson, Dallas, Tex.
Cecil H. Green, Julian D. Barksdale, Charles E. Weaver
Neal Hughes Potts, Wichita Falls, Tex.
W. A. Ver Wiebe, J. R. Berg, John W. Inkster
Wallace Lee Saultz, Midland, Tex.
V. E. Monnett, Carl A. Moore, F. A. Melton
Russell Melvin Seward, Jr., Farmington, N. M.
Joseph H. Markley, Jr., Edwin M. Rowser, R. H. Schweers
Jack Aaron Simon, Urbana, Ill.
Alfred H. Bell, L. E. Workman, Glen F. Brown
Keith Fulton Walker, Dallas, Tex.
V. E. Monnett, Ellis W. Shuler, Claude C. Albritton, Jr.
William Francis Yerington, Bakersfield, Calif.
Robert M. Kleinpell, Charles M. Gilbert, E. H. Vallat

FOR TRANSFER TO ACTIVE MEMBERSHIP

Robert Turner Bennett, New Orleans, La.
B. E. Bremer, Harry X. Bay, A. C. Trowbridge
Kathleen Stephens Keathley, Dallas, Tex.
Ellis W. Shuler, Claude C. Albritton, Reese L. Hayes.
Arthur Jack Oden, Dallas, Tex.
Henry C. Cortes, Paul E. Nash, J. C. Menefee

JOINT REGIONAL EXPLORATION MEETING, DALLAS, TEXAS, NOVEMBER 18–19, 1948

The Dallas Geological Society and the Dallas Geophysical Society have announced a joint meeting in Dallas, Texas, the feature of which will be a symposium on limestone reefs. The announcement follows.

A Joint Regional Exploration Meeting, sponsored by the Dallas Geological Society and the Dallas Geophysical Society, will be held in Dallas on November 18–19, 1948. The Adolphus Hotel will be headquarters for the meeting.

In order to make a reservation please notify the Adolphus Hotel immediately specifying that you wish to attend the regional meeting and indicating preferred room arrangement. Due to shortage of rooms it will be necessary to double up. If you have a preference please so indicate.

The meeting will be devoted to miscellaneous geophysical problems and a geological and geophysical symposium on the origin, development, occurrence, economic importance of and exploration for Limestone Reefs.

Technical sessions will be held Thursday and Friday, 9–12 A.M. and 2–5 P.M.

A dinner-dance will be held in the main ballroom of the Adolphus Hotel, Friday evening, November 19, with tickets costing $3.50 per person.

HOUSTON REGIONAL MEETING, DECEMBER 2–3, 1948

A regional meeting of the Association will be held in Houston, Texas, on December 2 and 3, 1948, at the invitation of the Houston Geological Society. A. F. CHILDERS, president of the Society, has announced appointment of the following committees and chairmen to have charge of arrangements.

General committee—GEORGE S. BUCHANAN, Sohio Petroleum Company
Technical program—HILLARD W. CAREY, Houston Natural Gas Corporation
Hotels and housing—CARLETON D. SPEED, JR., Speed Oil Company, 1315 Second National Bank Building
Finance—E. O. BUCK, National Bank of Commerce
Entertainment and dance—DONALD I. GAHAGAN, Pan American Producing Company
Publicity-program—J. BRIAN EBY, consultant, 1404 Esperson Building
Registration—FRANK J. GARDNER, Rinehart Oil News Company
Program—PAUL B. LEAVENWORTH, Gulf Oil Corporation

(The following is a copy of the announcement to be mailed to all members)

ANNOUNCEMENT

REGIONAL MEETING OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

Rice Hotel, Houston, Texas, December 2–3, 1948

A regional meeting of the American Association of Petroleum Geologists will be held at the Rice Hotel, Houston, Texas, on December 2 and 3, 1948.

For your convenience in making hotel reservations for the coming regional meeting of the American Association of Petroleum Geologists, in Houston, hotels and their rates are listed below. Use the form at the bottom of this page, indicating your first, second, and third choice. Because of the limited number of single rooms available, you will stand a much better chance of securing accommodations if your request calls for rooms to be occupied by two or more persons. All reservations must be cleared through the housing bureau. ALL REQUESTS FOR RESERVATIONS MUST GIVE DEFINITE DATE AND HOUR OF ARRIVAL AS WELL AS DEFINITE DATE AND APPROXIMATE HOUR OF DEPARTURE, ALSO NAMES AND ADDRESSES OF ALL PERSONS WHO WILL OCCUPY RESERVATIONS REQUESTED MUST BE INCLUDED.

Hotel	*One Person*	*Two Persons* *Double Bed*	*Two Persons* *Twin Beds*	*2-Room Suites* *Parlor and Bedroom*
RICE	\$4.00 to \$7.00	\$5.00 to \$8.00	\$6.00 to \$9.00	\$15.00
LAMAR	\$3.50 to \$5.00	\$5.00 to \$7.00	\$6.00 & \$7.00	\$12.00 to \$15.00
BEN MILAM	\$3.00 to \$6.00	\$4.00 to \$8.00		
SAM HOUSTON	\$2.25 to \$3.50	\$3.25 to \$4.50		
WM. PENN	\$2.75 to \$4.25	\$4.25 to \$5.75		
TEXAS STATE	\$3.00 to \$9.00	\$5.50 & up		

In the event that the hotel room-rate structure is changed prior to the meeting these rates will be changed accordingly.

ALL RESERVATIONS MUST BE RECEIVED BY NOVEMBER 15, 1948.

American Association of Petroleum Geologists, Hotel Reservations, Bruce Carter, Rice Hotel, Houston, Texas.

Please reserve the following accommodations for the regional meeting of the A.A.P.G. in Houston, Texas, on December 2 and 3, 1948.

Single Room............ Double-Bedded Room........... Twin-Bedded Room............

2-Room Suite........... Other Type of Room............

Rate: From \$........... to \$...........First choice hotel..............................

Second choice hotel..............................

Third choice hotel..............................

Arriving at Hotel (date).................... Hour ...........A.M. ...........P.M. ....

Leaving Hotel (date) .... Hour ...........A.M. ...........P.M. ....

THE NAME OF EACH HOTEL GUEST MUST BE LISTED. Therefore, please include the names of *both* persons for *each* double room or twin-bedded room requested. Names and addresses of all persons for whom your are requesting reservations and who will occupy the rooms asked for:

....

....

(Individual requesting reservations)

Name.................... Address.................... City & State....................

If the hotel of your choice is unable to accept your reservation the Housing Bureau will make as good a reservation as possible elsewhere provided all hotel rooms have not been taken.

ASSOCIATION DISTRICTS

The executive committee arranges the Association membership into geographic districts so that the members may elect district representatives on the business committee. This is in accordance with Article V of the by-laws.

ARTICLE V. DISTRICT REPRESENTATIVES

The executive committee shall cause to be elected district representatives from districts which it shall define by a local geographic grouping of the membership. Such districts shall be redesignated and redefined by the executive committee as often as seems advisable. Each district shall be entitled to one representative for each seventy-five members, but this shall not deprive any designated district of at least one representative. The representatives so apportioned shall be chosen from the membership of the district by a written ballot arranged by the executive committee. They shall hold office for two years, their term of office expiring at the close of the annual meeting.

In 1948 there are 25 districts, 23 of which are in the United States (Fig. 1), and one comprises Canada, and one South America.

Each district has at least one representative, elected by the individual members (full members, not associate members) residing in the district. This representative thus becomes a member of the Association business committee, which acts "as a council and advisory board to the executive committee and the Association."

In each district, with few exceptions, there is an organized geological society; in a few districts there are two or three societies. The "local" society is not an organized part of the A.A.P.G.; it is independent and self-governing. Usually, the society was organized before the A.A.P.G. district was designated. Most of the societies are officially affiliated with the A.A.P.G., and most of their members are members of the A.A.P.G., but the societies have

ASSOCIATION DISTRICTS
(January, 1948)

District	*Representatives*	*Members*
1. Amarillo	1	25
2. Appalachian	1	130
3. Canada	1	65
4. Capital	1	71
5. Corpus Christi	1	65
6. Dallas	2	158
7. East Oklahoma	4	343
8. Fort Worth	1	99
9. Great Lakes	3	170
10. Houston	6	458
11. Michigan	1	36
12. New Mexico	1	47
13. New York	2	163
14. Pacific Coast	6	514
15. Rocky Mountain	1	234
16. Shreveport	1	117
17. South America	2	201
18. Southeast Gulf	1	114
19. Southern Louisiana	1	107
20. Southern Permian Basin	3	232
21. South Texas	2	171
22. Tyler	1	37
23. West Oklahoma	2	217
24. Wichita	1	145
25. Wichita Falls	1	69
Total	47	3,088

A. A. P. G. DISTRICTS

FIG. 1

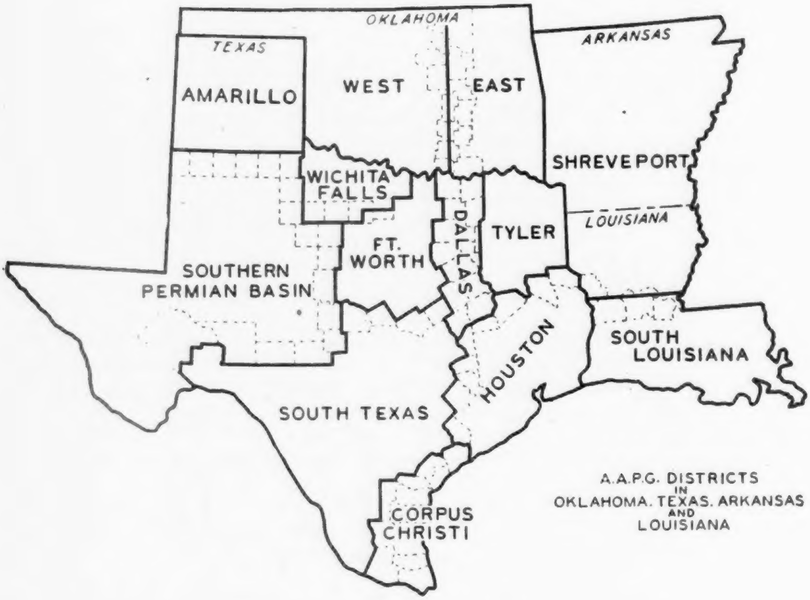


FIG. 2

no officially recognized voice in Association business. The A.A.P.G. district representatives are not elected by the societies. The societies and the Association are affiliated by the ties of common scientific purposes, professional activities, and membership.

GEOGRAPHIC DESCRIPTION OF DISTRICTS

Amarillo.—Panhandle of Texas. Its south boundary coincides with south line of these counties: Parmer, Castro, Swisher, Briscoe, Hall, and Childress.

Appalachian.—Ohio, West Virginia, western New York, western Pennsylvania, eastern Kentucky, and eastern Tennessee. Northeast boundary in New York coincides with east sides of Oswego, Onondago, Cortland, and Tioga counties; in Pennsylvania it coincides with east and south sides of Bradford, Sullivan, Lycoming, Clinton, Center, Mifflin, Huntingdon, and Bedford counties. Southwest boundary in Kentucky is north-south line west of Louisville; in Tennessee, it is north-south line west of Nashville.

Canada.—All of Canada.

Capital.—Delaware, Maryland, District of Columbia, Virginia, and North Carolina.

Corpus Christi.—Southern Gulf Coast of Texas. Includes counties of Calhoun, Refugio, Aransas, San Patricio, Jim Wells, Nueces, Kleberg, Brooks, Kenedy, Hidalgo, Willacy, and Cameron.

Dallas.—Texas counties of Grayson, Fannin, Collin, Hunt, Dallas, Rockwall, Kaufman, Ellis, Navarro, Limestone, Freestone, Leon, Robertson, west part of Van Zandt and Henderson west of north-south line drawn from southeast corner of Hunt County to south boundary of Henderson County. (This places Canton and Athens in Tyler district).

East Oklahoma.—Oklahoma east-west line of Kay County and southeastward from southeast corner of Kay County the area east of Arkansas River, and east of north-south range line between R. 6 E. and R. 7 E. (thus including Ponca City, Pawhuska, Cleveland, Oilton, Drumright, Bristow, Wewoka, Holdenville, Wapanucka, and Durant).

Fort Worth.—Texas counties of Cooke, Denton, Wise, south part of Jack to include Jacksboro, southeast part of Young to include Graham, Stephens, Palo Pinto, Parker, Tarrant, Johnson, Hood, Somervell, Erath, Eastland, Brown, Comanche, Mills, Hamilton, Bosque, Hill, McLennan, and Coryell.

Great Lakes.—States of Minnesota, Wisconsin, Iowa, Illinois, Indiana, Missouri, Kentucky west of Louisville, and Tennessee west of Nashville.

Houston.—Southeastern Texas Coastal Plain counties extending from the Gulf of Mexico on the southeast to and including the following counties on the north and west: Shelby, Nacogdoches, Angelina, Houston, Madison. Brazos, Washington, Austin, Colorado, Jackson, and Matagorda.

Michigan.—State of Michigan.

New Mexico.—Arizona and New Mexico.

New York.—New England states, New Jersey, eastern New York, and eastern Pennsylvania. West boundary in New York coincides with west sides of Jefferson, Lewis, Oneida, Madison, Chenango, and Broome counties; in Pennsylvania it coincides with west cr north sides of Susquehanna, Wyoming, Luzerne, Columbia, Montour, Northumberland, Union, Snyder, Juniata, Franklin, and Fulton counties.

Pacific Coast.—Washington, Oregon, Nevada, and California.

Rocky Mountain.—Montana, Idaho, Wyoming, Utah, and Colorado.

Shreveport.—Arkansas and northern Louisiana north of Township 4 North. (This places Alexandria in Southern Louisiana).

South America.—All of South America.

Southeast Gulf.—Mississippi, Alabama. Georgia, South Carolina, and Florida.

Southern Louisiana.—Southern Louisiana south of north side of Township 4 North, to include Alexandria.

Southern Permian Basin.—Western Texas extending east from the Rio Grande and New Mexico to and including the following counties: Brewster. Pecos, Crockett, Sutton, Kimble, Mason, McCulloch, Coleman, Callahan, Shackelford, Jones, Stonewall, King, Cottle, Motley, Floyd, Hale, Lamb, and Bailey.

South Texas.—Southern Texas extending northeast from the Rio Grande to and including the following counties: Terrell, ValVerde, Edwards, Kerr, Gillespie, Llano, San Saba, Lampasas, Bell, Falls, Milam, Burleson, Lee, Fayette, Lavaca, Victoria, Goliad, Bee, Live Oak, Duval, Jim Hogg, and Starr.

Tyler.—Northeastern Texas extending south and west of the state boundary to and including the following counties: Lamar, Delta, Hopkins, Rains, eastern Van Zandt to include Canton, eastern Henderson to include Athens, Anderson, Cherokee, Rusk, and Panola.

West Oklahoma.—Oklahoma west of north-south range line between R. 6 E. and R. 7 E. (thus including Ponca City, Pawnee, Cushing, Chandler, Shawnee, Seminole. Ada, Ardmore, Madill).

Wichita.—North Dakota, South Dakota, Nebraska, and Kansas.

Wichita Falls.—Counties of Hardeman, Foard, Wilbarger, Wichita, Clay, Montague, Knox. Baylor, Archer, Hasdell, Throckmorton, Young except southeast corner (thus placing Graham in the Fort Worth district), and Jack north of Jackson.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 10 (OCTOBER, 1948), P. 2000

MEMORIAL

CLARENCE J. PETERSON

(1885–1948)

Clarence J. Peterson, "Pete" to his many friends, died on May 8, 1948, in Amarillo, Texas, as result of a cerebral hemorrhage suffered a few days previously. He is survived by a sister, Mrs. Helen Peterson Hoyt of Honolulu. "Pete" had never married.

He was born at Kaneohe, Honolulu, Hawaii, April 3, 1885. He graduated from Stanford University in 1910 after four years of study in geology and mining. Thereafter his activities extended to areas in both local and foreign fields. During the 1910–1917 period he engaged in mine engineering work in California, Nevada, and Nicaragua, and in oil geologic work in Venezuela. In 1917 and again in 1923–1926 he served with Empire Gas and Fuel Company, or with related units of the Cities Service Company, as oil geologist in Mid-Continent and Rocky Mountain areas. During 1917–1922 he was similarly engaged in Kentucky and Mid-Continent areas for New York interests represented by Pemberton and Severy and by W. R. Hamilton. In 1927–1930 he was administrative geologist at Bartlesville, Oklahoma, for Cities Service Gas Company, and for the succeeding years chief geologist for the Texoma Natural Gas Company, Amarillo. He was a member of this Association since 1919.

With "Pete," doing a job meant doing it thoroughly, sparing no endeavor to observe and evaluate every detail himself or through the closest of contact with those assisting him. To him the handling of an assignment meant responsibility to his employer, to the department head with whom he might be serving, to those assisting, and above all to the determinable facts about matters under investigation. He served quietly without publicity-seeking or personal advertisement and, since his assignments involved results of confidential character, his reports were private and did not include contributions for publication. At times he supported his findings in the course of public commission or court hearings.

In the passing of "Pete" Peterson many have lost an "all-out" friend and the profession a worthy representative.

W. L. WALKER

Santa Monica, California
September 1, 1948

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 10 (OCTOBER, 1948), PP. 2001-2010

AT HOME AND ABROAD

NEWS OF THE PROFESSION

The Houston Geological Society has a special committee headed by PERRY OLCOTT of the Humble Oil and Refining Company, appointed by former Society president CHARLES H. SAMPLE, to work with FRANK A. HERALD who has been employed by the University of Texas Bureau of Economic Geology, JOHN T. LONSDALE, director, at Austin to supervise the obtaining and the publishing of factual and historical data on all the oil and gas fields of Texas. Other geological societies of Texas are also joining in this project.

W. GRANT BLANCHARD, formerly at Purcell, Oklahoma, has succeeded E. FLOYD MILLER with A. G. OLIPHANT, 1905 National Bank of Tulsa Building, Tulsa, Oklahoma.

The Third Annual Field Conference of the Wyoming Geological Association (Casper) was held at Lander, Wyoming, August 11–14. More than 250 registered on the first day. Seventy cars made up the automobile caravan, starting from Lander each day on itineraries in the Wind River Basin. The general chairman for all arrangements was PHILIP W. REINHART, of the Shell Oil Company, Inc.; F. HOWARD BRADY, of the Chemical and Geological Laboratories, Inc., was chairman of registration and the caravan; and JED B. MAEBIUS, of the Gulf Oil Corporation, was editor of the guide book. Officers of the Wyoming Geological Association, Casper, are: president, HENRY CARTER REA, consulting geologist; first vice-president, VICTOR H. KING, General Petroleum Corporation; second vice-president, W. STANLEY KNOUSE, Tide Water Associated Oil Company; and secretary-treasurer, H. E. SUMMERFORD, Chemical and Geological Laboratories, Inc.

CLARENCE G. BAILEY has severed his connections with the Shell Oil Company, Inc., to accept the position of district geologist with the Texas Pacific Coal and Oil Company in Sheridan, Wyoming.

WILLIAM LYNN KREIDLER has left the United States Geological Survey to accept a geological position with the Conselho Nacional do Petroleo, Salvador, Bahia, Brazil.

A. N. McDOWELL, of Texarkana, Arkansas, has accepted a position on the teaching staff of the geological department of Texas A. and M. College, College Station, Texas.

M. G. FREY has left the California Research Corporation to go to the department of geology at the University of Cincinnati, Cincinnati, Ohio.

MILTON R. SCHOLL, JR., recently employed by the Sun Oil Company, is in the department of geology of the University of Texas, Austin, Texas, as an instructor in geology.

G. FREDERICK SHEPHERD is chief geologist with the General American Oil Company of Texas, Dallas, Texas.

HENRY J. TYLER has left the Atlantic Oil Refining Company to join the Phillips Petroleum Company, Bartlesville, Oklahoma.

RUFUS J. LEBLANC recently resigned his position as chief of the geological branch of the Waterways Experiment Station in Vicksburg, Mississippi, to accept a position as senior research geologist with the exploration and production research division of the Shell Oil Company, Inc., in Houston, Texas.

CHARLES K. CLARK, geologist for 14 years for the Pure Oil Company and more re-

cently division geologist of the eastern producing division of that company, has resigned his position to join the Michigan Oil Company as geologist in charge of exploration and development. The Michigan Oil Company with headquarters at 403 Second National Bank Building, Saginaw, Michigan, is the newly formed producing subsidiary of the Bay Refining Corporation and the Bay Pipeline Corporation of Michigan, with producing properties in Michigan, Illinois, and Kansas.

FREDERIC H. LAHEE, chairman of the Association committee on statistics of exploratory drilling, and the geological and research counselor of the Sun Oil Company, Dallas, Texas, recently returned from a reconnaissance trip in the west and northwest. While on this trip he lunched with 50 members of the Alberta Society of Petroleum Geologists at Calgary, Alberta, Canada, to whom he spoke on the subject of classifying exploratory wells.

ROBERT B. CAMPBELL, consulting geologist, Gulf Hammock, Florida, attended the 18th International Geological Congress at London, where he represented the Florida Academy of Sciences. He will take part in field trips in the neighborhood of Bath, England, where "Strata Smith" developed important principles of stratigraphy, and numerous classic localities in the Western Highlands of Scotland.

As part of its regular program of sabbatical leave for research, Columbia University has granted CHARLES H. BEHRE, JR., professor of economic geology, a year's leave of absence in 1948–1949 to continue the study, begun 2 years ago, of the genesis, distribution, and geologic control of the mineral deposits of Mexico. During Professor Behre's absence two specialists in the same field have accepted invitations to lecture in the department of geology, with special emphasis on ore genesis and its influence on minerals search: T. S. LOVERING of the United States Geological Survey in October and DONALD M. DAVIDSON, consulting geologist, of the E. J. Longyear Company, in November.

HANS HLAUSCHEK, recently of Ploesti, may be reached in care of the Standard Française des Petroles, 82 Ave. des Champs Elysees, Paris.

The Geological Forum of the Pacific Section of the Association, Los Angeles, California, presented the following program at the Edison Building Auditorium, 601 West Fifth Street, Los Angeles, August 16: "Geology of Santa Cruz Island," by W. W. RAND, Union Oil Company; "History of the Development in the Cuyama Valley and Vicinity," by MARTIN VAN COUVERING, consultant; "Some Current Local Aspects in the Cuyama Valley," by JOSEPH EATON, consultant.

FRANK BRYAN, consulting geologist, Groesbeck, Texas, is co-author of the novel, *Scarlet Cockerel*, being released this September by William Morrow and Company, New York publishers, which was written at his country place in the large orchard he has planted on reclaimed farms in northern Choctaw County, Oklahoma.

M. M. MULHOLLAND, after 10 years in Colombia, with the Tropical Oil Company, has been transferred to domestic service with the Carter Oil Company and assigned to the eastern division office in Mattoon, Illinois.

GORDON HURD has resigned as district geologist for the Continental Oil Company to do consulting work. His address is 2916 Dahlia Street, Denver, Colorado.

MICHAEL B. MORRISS, recently with the J. S. Abercombie Company, Houston, is employed by the Continental Oil Company, San Antonio, Texas.

H. W. ROBBINS, of Hoover, Curtice, and Ruby, Inc., may be addressed: Companhia dos Petroleos de Portugal, Rua Castilho 9, Lisboa, Portugal.

SCHUYLER B. HENRY is with the Arabian American Oil Company, Dhahran, Saudi, Arabia.

STEWART BEVAN is with the Arabian American Oil Company, Dhahran, Saudi, Arabia.

J. F. ROMINGER, recently in the geology department at Northwestern University, is in the employ of the Carter Oil Company, Tulsa, Oklahoma.

J. C. HEGGBLOM has left the Bahamas Exploration Company, Ltd., at Nassau, to join the Mozambique Gulf Oil Company, Caixa Postal 69, Lourenco Marques (Mozambique, Portuguese East Africa).

PHILIP OXLEY has accepted the position of instructor in geology at Hamilton College, Clinton, New York.

HAROLD G. SEHNERT, JR., has joined the Sohio Petroleum Company at Evansville, Indiana. He was recently in the employ of the Sun Oil Company.

LYNN JACOBSEN has transferred from the geology department of the University of Oklahoma to the University of Kentucky, Lexington, Kentucky.

C. H. ACHESON is with the Tropical Oil Company at Bogota, Colombia.

R. T. BENNETT, formerly with The Texas Company, has moved to the geological department of the Arkansas Fuel Oil Company, Shreveport, Louisiana.

ANNE R. FRANK, no longer with the General Geophysical Company, is senior seismograph computer for the Tidelands Exploration Company, Houston, Texas.

WALTER YOUNGQUIST has received his Ph.D. degree in geology at the State University of Iowa, and has been appointed assistant professor of geology at the University of Idaho, at Moscow, Idaho, for the coming academic year.

NELSON B. POTTER has resigned from the Cities Service Company to accept a position as division geologist for the Bay Petroleum Corporation and will reside in Denver, Colorado.

ERNEST J. MURDOCH has resigned his position as assistant district geologist for the Atlantic Refining Company in Shreveport and is now employed by the Marine Oil Company as geologist in El Dorado, Arkansas.

R. W. CARTER has resigned his position as party chief for the Seismograph Service Corporation of Tulsa, Oklahoma, to accept one as geophysicist for the Union Producing Company of Shreveport, Louisiana.

J. D. AIMER, formerly district geologist for the Barnsdall Oil Company at Shreveport, Louisiana, is now employed by the Root Petroleum Company as chief geologist and is located in the principal office at Shreveport.

CHARLES A. RENFROE has left the Arkansas Geological Survey, where he has been employed as State petroleum geologist, and has accepted a position as associate professor of geology at the Texas Technological College in Lubbock, Texas.

OSCAR L. HATCHER, consulting geologist, has been appointed chief geologist with the Oklahoma Natural Gas Company, Tulsa.

GROVER E. MURRAY resigned, August 1, as geologist with the Magnolia Petroleum

Company, to accept a position as professor of stratigraphy at Louisiana State University, Baton Rouge. He was with the company at Jackson, Mississippi, 7 years.

RONALD K. DEFORD, chief geologist of the Argo Oil Corporation, Midland, Texas, resigned to become professor of geology at the University of Texas, Austin, effective September 15.

NORMAN HARDY has changed his address from the Standard Oil Company of California to the Richmond Exploration Company, Caracas, Venezuela.

ROBERT F. EBERLE has left the employ of the Superior Oil Company, to enter business for himself. His address is 1214 Parker Avenue, Evansville, Indiana.

SHERMAN A. WENGERD, associate professor of geology, University of New Mexico, Albuquerque, was back on active duty with the Navy, as a lieutenant commander early in September,—a 2-week training course, working in Denver, on maps of the Naval Petroleum Reserve No. 4 in Alaska.

CECIL HAGEN and RALPH B. CANTRELL announce their partnership as consultants in petroleum geology and engineering, specializing in the Gulf Coast, Texas, and Louisiana. Their office is in the Gulf Building, Houston, Texas.

DONALD A. GRAY, who operates the West Central Texas Sample Log Service, has changed his headquarters from 803 Dayton, Wichita Falls, Texas, to 4028 Boyd Street, Fort Worth, Texas, effective September 1, 1948.

GEORGE A. REED, who has been in the employ of the Gulf Oil Corporation, is now with the Skelly Oil Company, Wichita, Kansas.

R. W. EDMUND has resigned as associate division geologist with the Globe Oil and Refining Company to accept the position of associate professor of geology at Augustana College, Rock Island, Illinois.

LOUITA DODSON WILSON (*nee* Louita Garner Dodson) has resigned her position with the Venezuela Atlantic Refining Company, Caracas, and may be addressed at Del Rio, Texas. She married THOMAS C. WILSON of the same company, on August 7, and they attended the International Geological Congress in London, later spending 2 weeks in the Scottish Highlands.

THOMAS W. STERN is with the United States Geological Survey, Section of Geochemistry and Petrology, Washington, D. C.

EDWIN C. BUFFINGTON is with the United States Navy Electronics Laboratory, San Diego, California.

KENNETH W. GERMOND has changed his address from the Sun Oil Company, Dallas, to the Danciger Oil and Refining Company, Fort Worth, Texas.

CURRAN R. CAMPBELL has resigned his position as paleontologist for Stanolind Oil and Gas Company to become chief paleontologist with the Phillips Petroleum Company, 1046 City National Bank Building, Houston, Texas.

LAVON MARIE PETERS is with the Shell Oil Company, Inc., Tulsa, Oklahoma, since leaving the employ of the Gulf Oil Corporation at Midland, Texas.

The address of ANTHONY FOLGER is Room 208, Depto. de Exploracion, Petroleos Mexicanos, Avenida Juarez 95, Mexico City, D. F.

JOHN HILL DEFORD is in the employ of the Bay Petroleum Corporation, Midland, Texas. He was formerly with the Union Oil Company of California.

VIRGIL H. WELCH died at Tulsa, Oklahoma, September 6, at the age of 52 years. He had been in the employ of the Amerada Petroleum Corporation 25 years.

GARRETT A. MUILENBURG, after 32 years of continuous service at the Missouri School of Mines, may now be addressed at 2 Vichy Road, Rolla, Missouri.

R. E. HAYWARD has been working for the Socony-Vacuum Oil Company in Bogota, Colombia. He is now a graduate student in geology at the California Institute of Technology, looking forward to the M.S. degree.

JOHN S. BRADLEY, recently at Golden, Colorado, is in the department of geology at the University of Washington, Seattle, Washington.

M. H. L. KEENER has left the School of Geology at the University of Oklahoma, and is employed by the Pure Oil Company, at Fort Worth, Texas.

DONALD MACOMBER, JR., is working for the Shell Oil Company, Inc., Lake Charles, Louisiana.

JOHN G. VOIGHT, recently a senior student at the Texas A. and M. College, is employed by the Stanolind Oil and Gas Company in San Antonio, Texas.

Lieutenant Colonel HUBERT G. SCHENCK, chief of the Natural Resources Section, General Headquarters of the Supreme Commander for the Allied Powers, and SHERMAN K. NEUSCHEL (U. S.G.S.) chief of the Pacific Geological Surveys Engineer Office, General Headquarters, Far East Command, represented General Douglas MacArthur at the 18th International Geological Congress in London.

J. C. MARTIN, JR., has resigned his position as district geologist with the Texas Gulf Producing Company, Houston, Texas, to join the geological staff of the Bay Petroleum Corporation, Denver, Colorado.

The Houston Geological Society has invited the Association to hold a regional meeting in Houston, Texas, on December 2 and 3, 1948. Further announcement will appear in later issues of the *Bulletin*.

R. C. BOWLES, of the Standard Oil Company of Kansas, reported on the International Geological Congress recently held in London, at the first meeting of the Houston Geological Society, September 13.

HAROLD S. THOMAS has resigned as head of the department of geology and geography at Roosevelt College of Chicago and is now regional research geologist with the Phillips Petroleum Company in Bartlesville, Oklahoma.

The 15th annual meeting and field trip of the South Texas Section of the A.A.P.G., San Antonio, will be held in Mexico City, October 18–23, by invitation of Petroleos Mexicanos. The Hotel de Prado, Mexico City, is headquarters. DOUGLAS WEATHERSTON, 1604 Milam Building, San Antonio, Texas, is chairman of the general committee. The technical program is designed to present problems in exploration in Mexico and adjoining regions. One field trip on October 21–23 is scheduled through the Mexican oil fields by way of Poza Rica, Tampico, and Reynosa. Another goes to the volcano Parícutin on October 21–22.

R. J. Hughes, Jr., has resigned from Exploration Surveys, Inc., Dallas, Texas, and has accepted a position as assistant professor of geology at Mississippi State College, State College, Mississippi.

Donald Kelly, who has been with The Texas Company in the Wichita Falls district 21 years, has resigned to open a consulting office. He has been district geologist for The Texas Company during the past 13 years.

William B. Arper, Jr., of the Phillips Petroleum Company, Shreveport, Louisiana, is on leave of absence to work on his doctoral degree in geology at the University of Kansas, where he is assistant instructor in the department of geology.

L. J. Beckmann is in the employ of the Carter Oil Company, Oklahoma City, Oklahoma.

Charles DeBlieux has resigned from the Louisiana Land and Exploration Company to enter consulting work at 902 Baronne Building, New Orleans, Louisiana.

Henry L. Bond, recently with the Phillips Venezuelan Oil Company in Caracas, is in the geological department of the Phillips Petroleum Company at Shreveport, Louisiana.

H. P. Schaub has resigned from the Royal Dutch-Shell group after 10 years of service as a geologist in Venezuela and Cuba. He may be addressed at Box 2514, Stanford University, California.

Joseph J. Graham has left the department of geology at A. and M. College, College Station, Texas, to go to the department of geology at Stanford University, California.

Aden E. Stiles, formerly with the Carter Oil Company at Oklahoma City, Oklahoma, has joined the International Petroleum Company, Ltd., Talara, Peru.

John F. Barrett has left the Colombian Gulf Oil Company at Bogota, to work with the Compania Petrolera de Peten S. A., Guatemala, C. A.

Thomas J. Burnett, Jr., has terminated employment with the Tide Water Associated Oil Company, Houston, Texas. His home address is 2230 South Boulevard.

The Dallas Geological Society and the Dallas Geophysical Society will hold a joint regional meeting at Dallas, Texas, November 18 and 19.

The Pacific Section of the A.A.P.G. will hold its annual fall meeting at Pasadena, California, October 28–29.

The Geological Society of America meets in annual session in New York City, November 11–13.

The West Texas Geological Society field trip in the Big Bend region of Texas will be held on October 29–31.

The Petroleum Division of the A.I.M.E. holds its fall meeting in Los Angeles, California, October 14–15.

The regional meeting of the A.I.M.E. will be at El Paso, Texas, October 24–27.

The annual meeting of the A.I.M.E. will be in San Francisco, California, February 14–17, 1949.

HORACE G. RICHARDS, associate curator, department of geology and paleontology, Academy of Natural Sciences of Philadelphia, has returned from an expedition to collect fossils from Arctic Canada in the vicinity of the Mackenzie Delta. The trip was sponsored by the Academy of Natural Sciences and was aided by a grant from the American Philosophical Society.

The Shreveport Geological Society and the Ark-La-Tex Geophysical Society held a joint meeting on September 20, at the Louisiana Exhibit Building, Shreveport. A paper on "Geophysical Prospecting by Telluric Currents," was read by E. G. LEONARDON, of the Schlumberger Well Surveying Corporation and the Geolectric Corporation.

JAMES C. FREEMAN, Magnolia Petroleum Company, San Antonio, Texas, spoke on "Strand Line Accumulation of Petroleum," before the South Texas Geological Society, September 23.

DAVID DONOGHUE, Fort Worth, Texas, geologist, and consultant to Felix Mendoza, president of the National Petroleum Council of Colombia, has returned from consultations with officials of the Colombian Government, looking toward the revision of Colombian laws to lessen the difficulties of oil exploration in that country.

The Geological Forum of the Pacific Section of the Association presented the following program on September 20: "Tertiary Geology of the Uinta Basin, Utah," by IRVING T. SCHWADE, Richfield Oil Corporation; "Water Resources Problems of Ventura County, California," by R. L. RYAN, Ventura County Engineer; and "The Self-Potential Dipmeter," by M. L. LOY and R. F. PHILLIPS, Schlumberger Well Surveying Corporation.

PACIFIC SECTION ANNUAL FALL MEETING, PASADENA, OCTOBER 28–29

The Twenty-Fifth Annual Joint Fall Meeting of the Pacific Section of the American Association of Petroleum Geologists, the Pacific Section of the Society of Economic Paleontologists and Mineralogists, and the Pacific Coast District of the Society of Exploration, Geophysicists, will be held at the Huntington Hotel, Pasadena, California, on October 28 and 29.

The A.A.P.G. morning and afternoon sessions on Thursday and Friday will feature a series of papers on recent discoveries of new oil-producing basins and new fields in California, together with reports on recent developments in Canada, the Rocky Mountain area, and Arabia.

Among the highlights of the two-day fall meeting will be the Thursday luncheon, the dinner meeting of the S.E.P.M. on Thursday evening, and the formal dinner dance on Friday evening which will terminate the meeting.

SAM STEWART, *publicity chairman*

EXECUTIVE COMMITTEE, PACIFIC SECTION, A.A.P.G.

President, WILLIAM P. WINHAM	Vice-Pres., HARVEY W. LEE
Sec.-Treas., PETER H. GARDETT	Past-Pres., MARTIN VAN COUVERING

EASTERN SECTION MEETING, NEW YORK, SEPTEMBER 14

The first fall meeting of the Eastern Section of the A.A.P.G. was held at the Mining Club, New York City, on the evening of September 14, under the chairmanship of Section president, W. P. HAYNES. There were 28 members and 6 visitors present, making a total attendance of 34. Following the dinner, there was a short business session, during which the election of next year's officers was successfully concluded as follows.

President:	Hollis D. Hedberg
Vice-President:	Douglas A. Greig
Secretary:	G. F. Kaufmann
Treasurer:	G. Marshall Kay (for 2d year)

John Haworth introduced the speaker of the evening, H. R. Tainsh, chief geologist in Burma for the Burmah Oil Company, whose subject was entitled, "The Regional Geology of Burma in Relationship to Its Oil Fields."

Douglas A. Greig, *Secretary*

TEXAS BUREAU OF ECONOMIC GEOLOGY WELL SAMPLE LIBRARY

John T. Lonsdale, director of the Bureau of Economic Geology, The University of Texas has announced recently that the Well Sample Library of the Bureau of Economic Geology now offers increased facilities for study of two million individual samples representing 25,000 oil, gas, and water wells from every section of the state. This collection, in its new location at the Off-Campus Research Center of The University of Texas, now weighs approximately 200 tons, covers 11,050 square feet of floor space, occupies 16,000 cubic feet of shelf space, and, in length of geologic sections represented, measures approximately 10,000 miles.

Extensive provisions have been made and are being projected for accommodating visiting geologists who wish to conduct full-scale research programs at the Well Sample Library.

A general index of all oil, gas, and water wells in the Library's collections, to be published soon, will be of interest to the oil industry. All wells in the collection will be listed in this index by county, and, within each county, alphabetically by company and fee owner. The sample ranges of every well will be noted. Included in the index will be a list of wells for which duplicate samples are on hand. These duplicate samples may be obtained for permanent possession by educational institutions, oil companies, or individuals upon request. The index will also include a list of certain surface samples on file at the Library for examination and study.

ORGANIZATION OF THE SEISMOLOGICAL SOCIETY OF AMERICA

In the July, 1948, issue of the *Bulletin* in an interesting paper entitled "Some Notes on Geology and Geologists, 1907–1947," by Hugh D. Miser, the Seismological Society of America was listed (p. 1340) as organized in 1910. As one of the original members of that society I would like to make a correction. The original meeting called by A. G. McAdie to consider the desirability of organizing such a society was held in San Francisco, August 30, 1906. Professor George Davidson was elected temporary chairman and George D. Louderback temporary secretary, and the chairman was authorized to appoint a committee on organization to prepare a constitution. At a meeting held November 20, 1906, the constitution was adopted and a board of directors elected. On December 1, 1906, the board met and elected the constitutional officers of the society for the ensuing year: George Davidson, president; A. C. Lawson, T. J. J. See, and A. G. McAdie, vice-presidents; George D. Louderback, secretary; J. N. LeConte, treasurer. Whichever date one selects as that of the organization of the society, it was in 1906, and the society has had continuous existence since that time. Its regular bulletin did not start publication until 1911, and is now in its 38th volume.

George D. Louderback

University of California, Berkeley
September 22, 1948

H. W. GILES is no longer with the Gulf Research and Development Company. He is in the employ of the Canadian Gulf Oil Company, Cardston, Alberta.

LEO WEINGEIST has left the Louisiana State University to engage in work in the geological laboratory of the Creole Petroleum Corporation, Caracas, Venezuela.

CHARLES HENRY ISE is geologist with the Southern Minerals Corporation, Midland, Texas.

DON L. FRIZZELL, recently at the University of Texas, is at the Missouri School of Mines, Rolla.

CHARLES C. BATES is with A. H. Glenn and Associates, meteorological consultants, Washington, D. C.

HOMER JENSEN is chief of the magnetometer division of the Aero Service Corporation, Philadelphia, Pennsylvania.

ROBERT C. HILL is head of the electrical department of the Eastman Oil Well Survey-Company, Long Beach, California.

DONALD I. LAWLESS has changed from the El Dorado Refining Company, El Dorado, Kansas, to the Bishop Oil Company, Wichita, Kansas.

C. C. HARTER, JR., recently with the Continental Oil Company, Midland, Texas, is now with DeGolyer and MacNaughton, Continental Building, Dallas, Texas.

R. F. RUTSCH has been named professor of paleontology and applied geology at the University of Berne, Switzerland. He is also vice-president of the Association Suisse des Géologues et Ingénieurs du Pétrole.

J. W. SULLIVAN has left The Texas Company and is now with the Southern Minerals Corporation, Corpus Christi, Texas.

ROY MEYRICK PRICE JONFS is geologist for the Amerada Petroleum Corporation, Calgary, Alberta.

EARLE N. ARMSTRONG is in the employ of the Cisco Hydrocarbon Corporation, Houston, Texas.

W. DALE GOODRICH, formerly with the Mid-Continent Petroleum Corporation, Tulsa, Oklahoma, is employed by the El Dorado Refining Company, Wichita, Kansas.

GUILLERMO RODRIGUEZ E is at Palo Alto, California, taking post-graduate courses at Stanford University.

ALFRED G. FISCHER, recently at the University of Rochester, is on the staff of the department of geology at the University of Kansas, Lawrence, Kansas.

WILHO J. KIVI, recently with the Mountain Fuel Supply Company, Rock Springs, Wyoming, is a graduate student in geology at Princeton University, Princeton, New Jersey.

T. W. NOON, JR., is on leave of absence from The Texas Company, to study at Harvard University.

EDGAR M. PILKINTON, deputy supervisor of the Mid-Continent region, United States Geological Survey, with headquarters in Tulsa, Oklahoma, has been made supervisor of

all unit plan work of the Survey in the United States and Alaska. He is now at 3232 Federal Works Building, Washington, D. C.

W. E. Wrather, director of the United States Geological Survey, Washington, D. C., spoke in his capacity as president of the American Institute of Mining and Metallurgical Engineers, on "Outlook for Mineral Supplies," at a meeting of the Mid-Continent Section of the A.I.M.E., at Lorton Hall, University of Tulsa, September 30. Wrather was president of the A.A.P.G. in 1922.

Henry H. Gray has moved from the Pennsylvania State College to Kent State College, Kent, Ohio.

Alvin Dale Turquette has left the Phillips Petroleum Company to join the Globe Oil and Refining Company as district geologist at Oklahoma City, Oklahoma.

C. G. Dickinson has left the Shell Oil Company, Inc., to enter the employ of the Forest Oil Corporation, San Antonio, Texas.

Ray E. Morgan is associate professor of economic geology at the University of Missouri School of Mines and Metallurgy at Rolla, following his resignation from chairmanship of the mining and geology department of the West Virginia Institute of Technology.

Emile Rod resigned from the Caribbean Petroleum Company and has joined the Compania Petrolera de Peten S. A. at Guatemala.

Fred M. Schall, Jr., has resigned his position as geologist with The Texas Company in New Orleans and has accepted a position as district geologist with the Big Chief Drilling Company, 620 Ardis Building, Shreveport, Louisiana.

Claude E. ZoBell, professor of marine microbiology at the Scripps Institution of Oceanography of the University of California, La Jolla, has been elected president of the American Society of Limnology and Oceanography for the coming year.

L. K. Lancaster, who recently resigned as manager of exploration for the Midland and Abilene districts of Seaboard Oil Company of Delaware to accept the position of chief geologist with the Star Oil Company, Inc., Dallas, Texas, has been elected a director and vice-president of the Star Oil Company, Inc., and of the Mars Drilling Corporation. The company address is 2310 Mercantile Bank Building, Dallas.

William Eliot Ranney has left the Sohio Petroleum Company to become a consulting geologist at Shreveport, Louisiana.

Clarence Symes, Jr., formerly with the Sinclair Prairie Oil Company, is now with the Sunray Oil Company, Midland, Texas.

Fred S. Honkala has moved from the University of Michigan to the department of geology at the Montana State University, Missoula, Montana.

John H. Webb has resigned his instructorship at the University of Oklahoma. He is now employed as regional geologist by the Phillips Petroleum Company. His home address is 2089 South Johnstone, Bartlesville, Oklahoma.

H. R. Tainsh, senior geologist Burma, of the Burmah Oil Company, is in the United States this fall. In the course of his visits to the oil fields, he is delivering a paper on the "Geology and Principal Oil Fields of Burma," at meetings of several of the geological societies in New York, Houston, Fort Worth, Tulsa and elsewhere.

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

THE SOCIETY OF EXPLORATION GEOPHYSICISTS

President - - - - - - - L. L. Nettleton
Gravity Meter Exploration Co.
1348 Esperson Bldg., Houston, Tex.
Vice-President - - - - - Andrew J. Gilmour
Amerada Petroleum Corporation
Box 2040, Tulsa, Oklahoma
Editor - - - - - - - - M. King Hubbert
Shell Oil Company, Inc.
Houston, Texas
Secretary-Treasurer - - - - - E. V. McCollum
E. V. McCollum and Company
515 Thompson Building, Tulsa, Oklahoma
Past-President - - - - - - - Cecil H. Green
Geophysical Service, Inc.
1311 Republic Bank Building, Dallas, Texas
Business Manager - - - - Colin C. Campbell
Room 210, 817 South Boulder, Tulsa, Oklahoma
P.O. Box 1614

CALIFORNIA

PACIFIC SECTION AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

President - - - - - - William P. Winham
Standard Oil Company of California
Box 2437, Terminal Annex, Los Angeles 54
California
Vice-President - - - - - - - Harvey W. Lee
Union Oil Company, 617 W. 7th St.
Los Angeles 14, California
Secretary-Treasurer - - - - - P. H. Gardett
General Petroleum Corp., 108 W. 2d St.
Los Angeles 12, California

Monthly meetings. Visiting geologists are welcome.

COLORADO

ROCKY MOUNTAIN ASSOCIATION OF GEOLOGISTS

DENVER, COLORADO

President - - - - - - - - C. E. Manion
Consulting Geologist
1740 Grape Street
1st Vice-President - - - - - - L. Brundall
Geophoto Services
305 E & C Building
2d Vice-President - - - - - - - S. W. Lohman
U. S. Geological Survey
136 New Customhouse
Secretary-Treasurer - - - - Kirk C. Forcade
Frontier Refining Company
410 Boston Building

Evening dinner (6:30) and technical program (8:00) first Tuesday each month or by announcement.

FLORIDA

SOUTHEASTERN GEOLOGICAL SOCIETY

Box 841
TALLAHASSEE, FLORIDA

President - - - - - - - - - Paul L. Applin
U. S. Geological Survey
Vice-President - - - - - James L. Martin, Jr.
Sinclair Prairie Oil Company
Secretary-Treasurer - - - Eleanor T. Caldwell
Humble Oil and Refining Company,
Box 506

Meetings will be announced. Visiting geologists and friends are welcome.

ILLINOIS

ILLINOIS GEOLOGICAL SOCIETY

President - - - - - - - - - - C. E. Brehm
C. E. Brehm Drilling & Producing
Mt. Vernon
Vice-President - - - - - - - Joseph Neely
Magnolia Petroleum Company
Box 535, Mt. Vernon
Secretary-Treasurer - - - - Halbert H. Bybee

Meetings will be announced.

INDIANA-KENTUCKY

INDIANA-KENTUCKY GEOLOGICAL SOCIETY

EVANSVILLE, INDIANA

President - - - - - - - - - - E. J. Combs
Sun Oil Company, Box 717
Vice-President - - - - - - Maynard Rogers
Independent, 417 Court Building
Secretary-Treasurer - - - - - D. G. Sutton
Sun Oil Company, Box 717

Meetings will be announced.

KANSAS

KANSAS GEOLOGICAL SOCIETY

WICHITA, KANSAS

President - - - - - - - - - - L. C. Hay
Independent, 703 Union Nat'l. Bank Bldg.
Vice-President - - - - - - - Don W. Payne
Sinclair Prairie Oil Company
Secretary-Treasurer - - - Shirley E. Lenderman
Stanolind Oil and Gas Company

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Noon luncheons, first and third Monday of each month at Wolf's Cafeteria. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka. Visiting geologists and friends welcome.

LOUISIANA

NEW ORLEANS GEOLOGICAL SOCIETY

NEW ORLEANS, LOUISIANA

President - - - - - - - - - Joe B. Hudson
Humble Oil and Refining Company
Vice-President and Program Chairman - - -
- - - - - - - - - - - Fred S. Goerner
California Company, 1818 Canal Building
Secretary-Treasurer - - - - - Ame Vennema
Schlumberger Well Surveying Corporation

Meets the first Monday of every month, October-May, inclusive, 12 noon, St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

PENNSYLVANIA

PITTSBURGH GEOLOGICAL SOCIETY
PITTSBURGH, PENNSYLVANIA

President - - - - - - - - - John T. Galey
Independent, Box 1675
Vice-President - - - - - - - W. B. Robinson
Gulf Research and Development Company
Box 2038
Secretary - - - - - - - - James C. Patton
Equitable Gas Company
610 Wood St.
Treasurer - - - - - - - - Sidney S. Galpin
Peoples Natural Gas Company
545 William Penn Place

Meetings held each month, except during the summer. All meetings and other activities by special announcement.

TEXAS

ABILENE GEOLOGICAL SOCIETY
ABILENE, TEXAS

President - - - - - - Frank B. Conselman
Consulting Geologist
Vice-President - - - - - - - - J. R. Day
Pan American Production Company
Secretary-Treasurer - - - - Riley G. Maxwell
Consulting Geologist
Box 1939

Meetings: 2d Thursday of each month, 7:30 P.M., Wooten Hotel.

DALLAS GEOLOGICAL SOCIETY
DALLAS, TEXAS

President - - - - - - Raymond A. Stehr
Seaboard Oil Company
1400 Continental Building
Vice-President - - - - - - - - John T. Rouse
Magnolia Petroleum Company
P.O. Box 900
Secretary-Treasurer - - - - - H. V. Tygrett
The Atlantic Refining Company
P.O. Box 2819
Executive Committee - - - - - Barney Fisher
Comanche Corporation
406 Continental Building

Meetings: Monthly luncheons and night meetings by announcement.

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - - - - R. H. Schweers
The Texas Company
Box 1720
Vice-President - - - - - - - F. H. Schouten
Stanolind Oil and Gas Company
Box 1410
Secretary-Treasurer - - - Millicent A. Renfro
Texas Pacific Coal and Oil Company, Box 2100

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

CORPUS CHRISTI GEOLOGICAL SOCIETY
CORPUS CHRISTI, TEXAS

President - - - - - - - - - H. D. McCallum
Humble Oil and Refining Company, Box 1271
Vice-President - - - - - Norman D. Thomas
Pure Oil Company
Secretary-Treasurer - - - - - James D. Burke
Seaboard Oil Company of Delaware, Box 601

Regular luncheons, every Thursday, Terrace Annex Room, Robert Driscoll Hotel, 12:00. Special night meetings by announcement.

EAST TEXAS GEOLOGICAL SOCIETY
TYLER, TEXAS

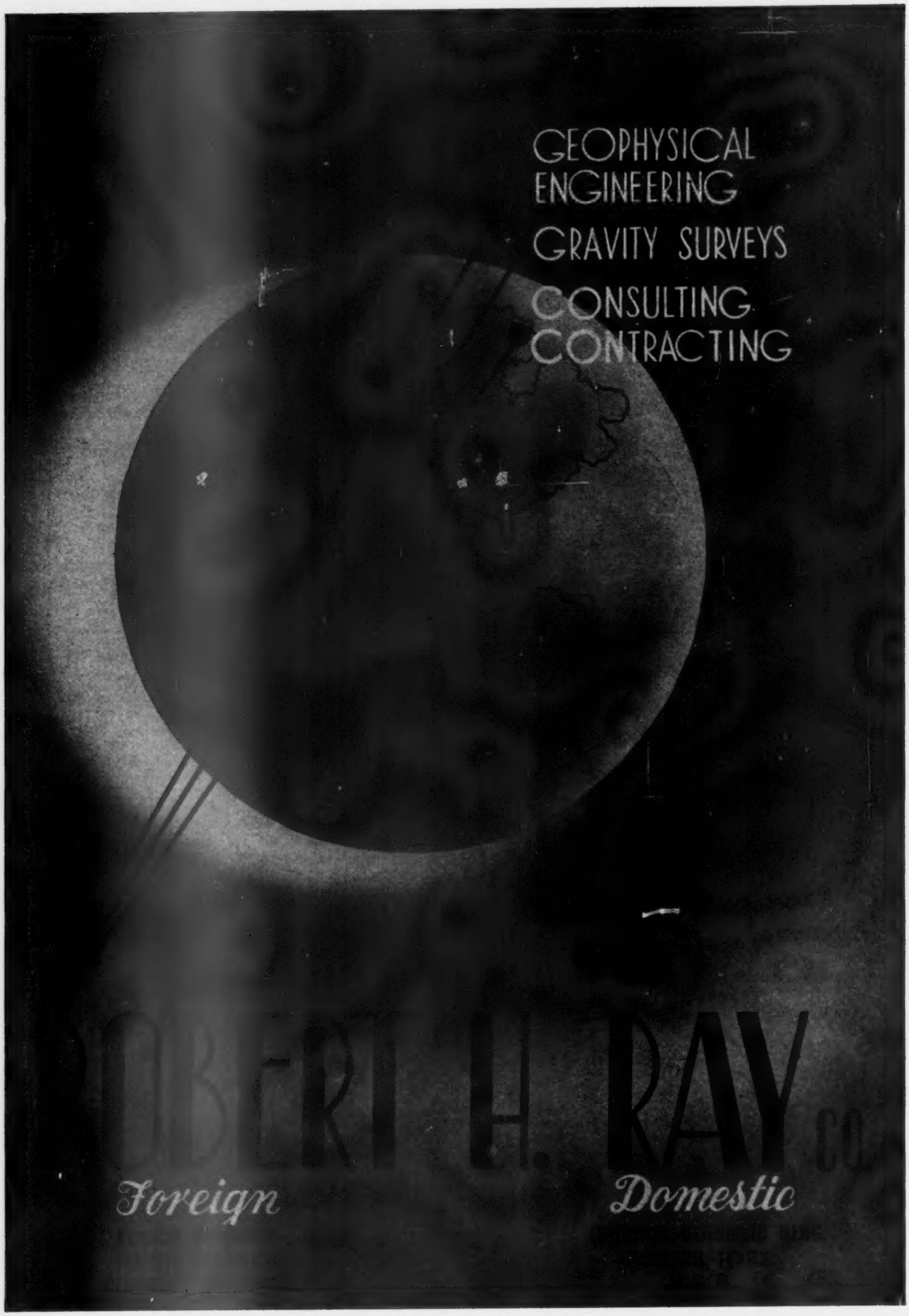
President - - - - - - - - - P. S. Schoeneck
Atlantic Refining Company
205 Manziel Building
Vice-President - - - - - - - - J. C. Price
Magnolia Petroleum Company
Box 780
Secretary-Treasurer - - - - - - G. C. Clark
Stanolind Oil and Gas Company
Box 660

Luncheons: Each week, Monday noon, Blackstone Hotel.
Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

President - - - - - - - - - A. F. Childers
Gulf Oil Corporation, Box 2100
Vice-President - - - - - Hershal C. Ferguson
Consultant, 935 Esperson Building
Secretary - - - - - - - - - - R. R. Rieke
Schlumberger Well Surveying Corporation
Treasurer - - - - - - - - Mary L. Holland
Stanolind Oil and Gas Company

Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Rice Hotel. For any particulars pertaining to the meetings write or call the secretary.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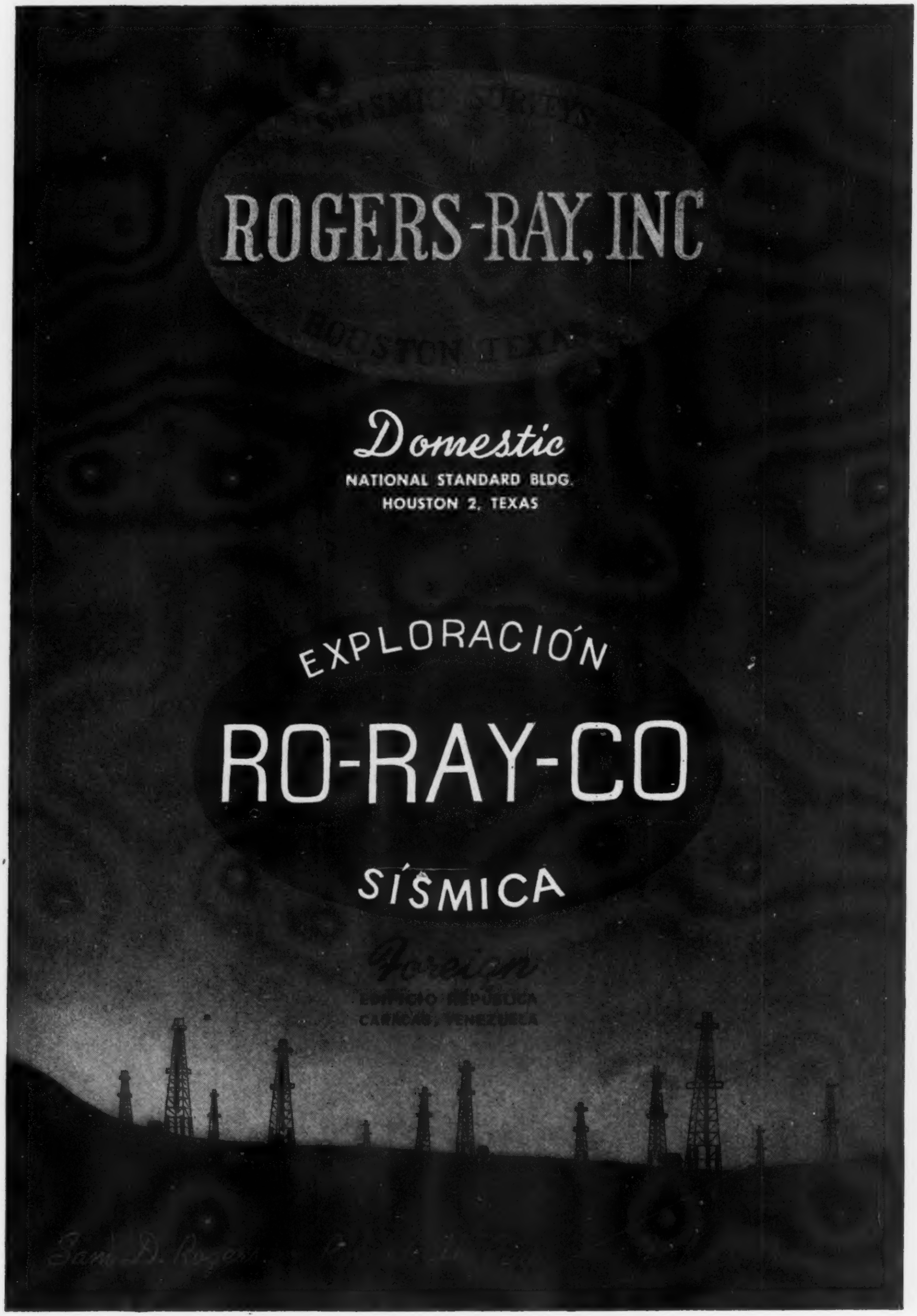
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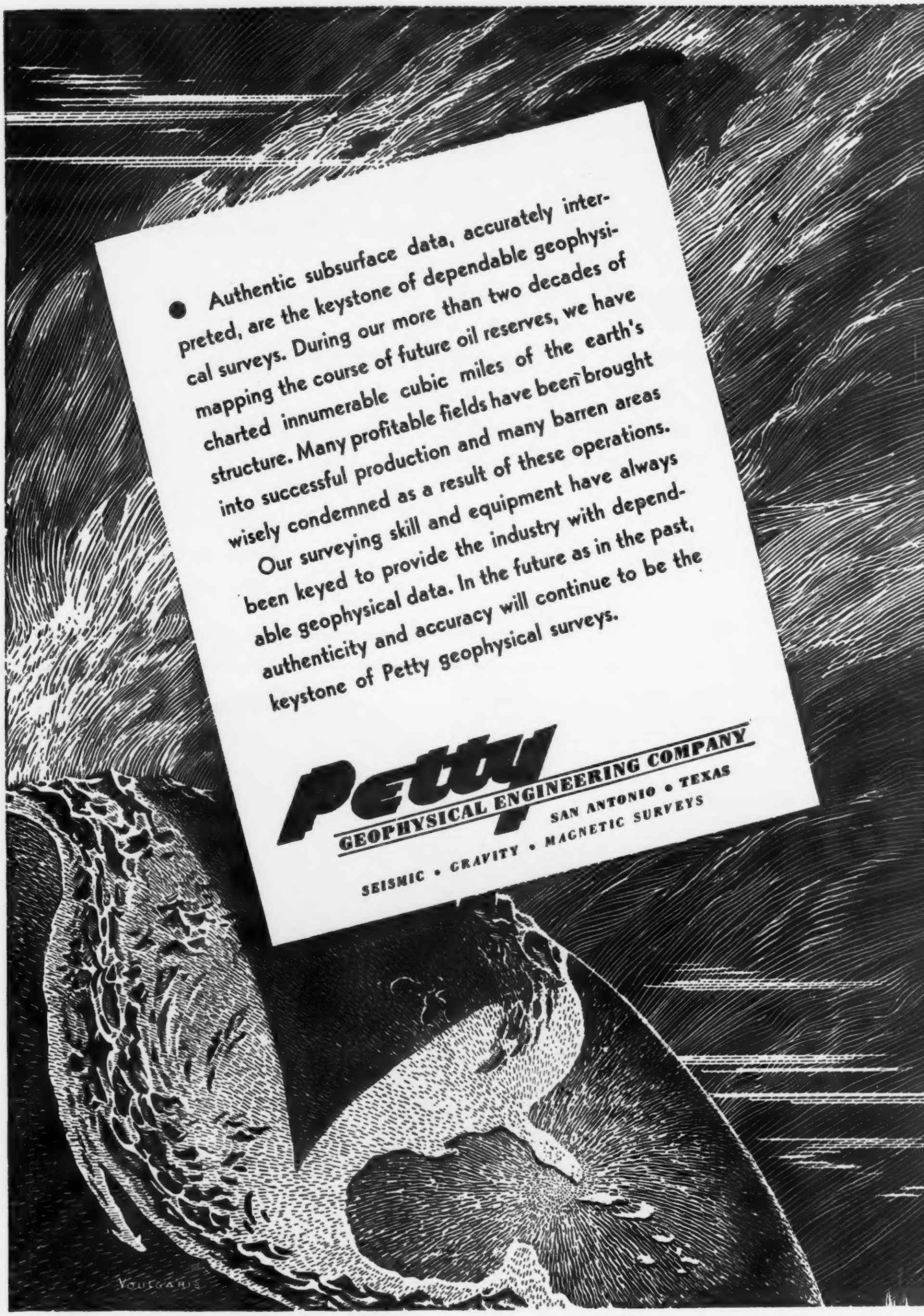
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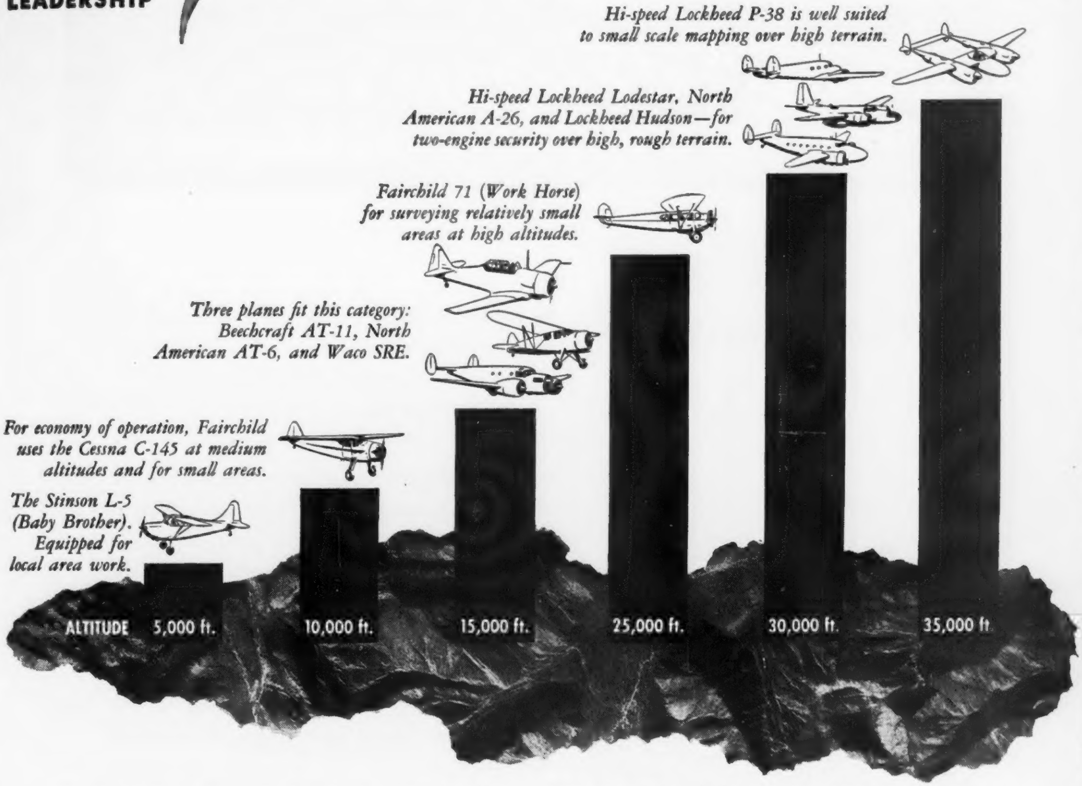

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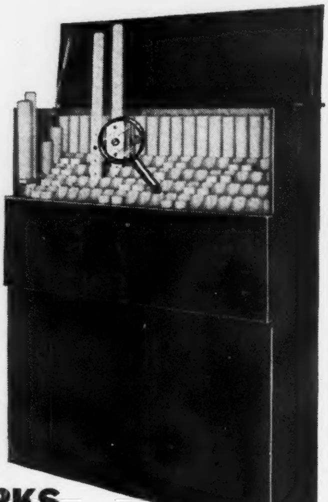

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